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MAXIMUM PERMISSIBLE CONCENTRATION OF RADIOISOTOPES IN AIR AND WATER FOR SHORT PERIOD EXPOSURE

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MAXIMUM PERMISSIBLE CONCENTRATION OF RADIOISOTOPES IN AIR AND WATER FOR SHORT PERIOD EXPOSURE

By

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INTRODUCTION

The National[1] and International[2] Committees on radiation protection have agreed upon maximum permissible concentrations (MPC) of radioisotopes in air and water for continuous exposure. For most radioisotopes, a state of equilibrium is reached between the concentration of the radioactive material in the environment and in the body organs as a result of continuous exposure. Although most of the radioisotopes reach this state of equilibrium in a few weeks or months, natural thorium, Pu^{239}, Sm^{151}, and Ra^{226} are exceptions, reaching 34%, 34%, 36%, and 67% of equilibrium, respectively, during the maximum period of exposure, assumed to be 70 years. Many radioactive materials are relatively insoluble, and the fraction entering the blood stream following ingestion or inhalation is small so that the gastrointestinal (GI) tract becomes the critical body tissue rather than the kidney, bone, liver, or other body organ[2]. Of the 355 MPC values listed in the ICRP Handbook[2], 71% of those for ingestion, and 41% of those for inhalation refer to the GI tract as the critical organ—meaning that the GI tract receives the maximum permissible dose rate of 0.3 rem/wk at a lower MPC value than that for any other body organ. It was assumed in these calculations that the radioactive material remains in the GI tract only 3½ hours, so a condition of equilibrium is reached between the environment and the GI tract in a few days.

The purpose of this report is to extend the method of calculation used in the ICRP Handbook[2] to estimate the MPC values or the maximum permissible intake (MPI) of these same radioactive materials for a single exposure. Since the concentration of material in the GI tract reaches equilibrium with that in air and water in a few days, one might suspect that the GI tract frequently would become the critical body organ for short periods of exposure. Another body organ likely to receive a high exposure and as a consequence become the critical body organ for single exposure is the lung. A preliminary investigation[3]

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indicated that for short periods of exposure the lung is the critical body organ for about 50% of the radioisotopes when the permissible dose is set as 0.3 rem during the week following the exposure and for 83% of the radioisotopes when the permissible dose is set as 0.3 x 52 or 15.7 rem during the ensuing year. In most of the other cases the GI tract is the critical body organ. Therefore, in this study considerable attention is given to the lung and the GI tract as the most probable critical body organs in establishing MPI values for a single exposure.

Since no official MPI values for single exposures have been agreed upon, a number of criteria will be examined and several tables of values based on various assumptions will be given in the hope that the reader will examine these critically and offer suggestions which will be helpful in making the final selection of the MPI values for single exposure.

The MPC values for continuous exposure have been useful in setting the average maximum permissible concentration of the radionuclides in air and water for occupational exposure, and following a recommendation of the National[1] and International[2] Committees on Radiation Protection, it has been common practice to set the MPC for environmental exposure at 1/10th of the occupational exposure values. Much of the biological data used in establishing the continuous exposure MPC values were incomplete, and in many cases animal data were of questionable application to human exposure. Also many of the assumptions made in these calculations were at best poor approximations; nevertheless, these MPC values are serving a useful purpose in that they indicate what are considered to be safe values based on the most reliable information presently available. Since thousands of people are working regularly with radioactive materials, these values are invaluable as a day-to-day guide in maintaining the concentrations of radioactive materials in air and water at what are considered to be safe occupational levels, and the radioactive wastes discharged from these operations into the environment are kept at an average concentration less than 1/10th of these values. Also upper limits are given in the handbooks[1,2] for the maximum permissible body burden of these radioactive materials corresponding to the maximum permissible concentrations (MPC) for continuous occupational and environmental exposure.

Although continuous exposure (MPC) values are necessary for all work with radioactive material, they do not answer many questions relative to the hazards associated with the occasional accident or spill of a radioactive material, and the resultant exposure of short duration--usually referred to as a single exposure. Also, in the design of laboratories for work with radioactive materials[4]; in the passage of legislation for the control of radiation hazards[5]; in the establishment of regulations for the shipment of radioactive materials[6]; and in many other similar areas of interest, there has been a considerable need for a reliable criterion to serve as a basis for grouping the various radioactive isotopes into categories of Very Dangerous, Moderately Dangerous, and Slightly Hazardous materials.

There are many factors that determine the relative hazards associated with the accidental spill of a radioactive material such as the physical state (solid, liquid, or gas), the solubility, the volatility, the specific activity, the biological damage that may result from the inhalation or ingestion of the material, etc. This account is limited to a discussion of the relative biological hazards associated with the various radioisotopes following an

accidental spill, assuming each to be present in a common physical and chemical form. The calculations are based only on inhalation of the radioactive material or passage into the body as the result of a contaminated wound. Ingestion is not considered since preliminary studies indicated a much greater internal exposure hazard from inhalation and injection than from ingestion. In event of an inhalation accident, it is assumed that part of the material is retained in the respiratory tract where it presents a lung hazard and a portion is swallowed directly or brought up from the bronchus by the cilia and swallowed where it presents a hazard either to the GI tract itself or some other body organ such as kidney, thyroid, bone, etc. One of these body organs may become the critical body tissue as a result of the absorption of the radioactive material through the intestinal wall and deposition in the organ in a large concentration so that it receives the major absorbed dose of radiation. Another type of serious accident with radioactive material may occur as a result of getting radioactive material into the body by way of a puncture wound, an open sore, or in some cases through the intact pores of the skin. One of the more common single exposure accidents is the result of puncture wounds with contaminated glassware. It is to be hoped that the values given in these tables may aid in the selection and establishment of suitable maximum permissible single exposure values that are applicable to most accidents with radioactive materials, and that this grouping of the radionuclides in the order of increasing radiation hazard may serve as the basis for properly placing them in categories of Very Dangerous, Moderately Dangerous, and Slightly Hazardous.

GENERAL ASSUMPTIONS AND NOMENCLATURE

In estimating the maximum permissible single exposure values for the various radionuclides, the characteristics of the standard man assumed are those outlined in the National[1] and International[2] Handbooks on internal dose and summarized as follows:

(1) Mass m of the body organs in grams and effective radius, x, in cm

	(g)	(cm)		(g)	(cm)
total body	7×10^4	30	lungs	1×10^3	30
muscle	3×10^4	30	kidneys	300	7
fat	1×10^4	20	spleen	150	7
bone	7×10^3	5	thyroid	20	3
blood	5.4×10^3	--			
skin	2×10^3	0.1			
liver	1.7×10^3	10			
GI tract	1.6×10^3	--			
small intestine	1100	30			
stomach	250	10			
lower large intestine	150	5			
upper large intestine	135	5			

(2) Time

Period of inhalation $t_1 = 8$ hours

Period of injection $t_1 = 0$

Period of permissible exposure, t_2

The following three cases are considered:

$t_2 = 7$ days

$t_2 = 1$ year

$t_2 = 70$ years

When the GI tract is the critical organ, only the one exposure period is considered, e.g., $t_2 = 7$ days.

(3) Permissible Dose, D. Three cases are considered:

D = 0.3 rem for $t_2 = 7$ days

D = 15.7 rem for $t_2 = 1$ year

D = 150 rem[a] for $t_2 = 70$ years

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a It is to be observed that this value is considerably less than 15.7 x 70. This reduction is deliberate and based on the assumption of the authors that the lifetime dose should not exceed 150 rem.

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(4) Absorbed energy per disintegration, $\Sigma(bE)(RBE)N$

In calculating the values of $\Sigma(bE)(RBE)N$, the relative biological effectiveness (RBE) was set equal to 1 for β^-, β^+, $\bar{e}$, X- and γ-radiation, 10 for α, and 20 for the recoil ions. The nonuniform distribution factor, N, was set equal to 1 in all cases except for the ionizing particles emitted in the bone, in which case it was set equal to 5. P^{32} and Ra^{226} were exceptions to this rule in that N was taken as 1. The value of $\Sigma(bE)(RBE)N$ was reduced by a factor of 2 for all calculations based on the GI tract in order to account for the fact that the walls of the GI tract are irradiated mostly from only one-half the solid angle. The calculation of $\Sigma(bE)(RBE)N$ for the GI tract makes correction for the absorption of some of the radioactive material through the wall of the small intestine and for the decay of the parent and growth of a radioactive daughter—if there is one—as the contaminated material passes through the GI tract during a 31-hour period. (See Appendix for details).

The values of $\Sigma(bE)RBE)N$ may be found as follows:

a) For Case 1 dealing with inhalation of soluble radioactive material, use Table 5 of ICRP Handbook[2], and column 5 (the values outside parenthesis) to find $\Sigma(bE)(RBE)N$ for organ listed in column 4.

b) For Case 2 dealing with injection of soluble radioactive material, use same references as for Case 1 above.

c) For Case 3 dealing with injection of insoluble radioactive material, it is assumed the effective diameter, X, of the contaminated tissue in the wound is 0.1 cm. The value of X determines the fraction of the γ-energy absorbed in the wound and values of Σ(bE)(RBE)N have not been given in the ICRP Handbook[2] in this case. Therefore, they are calculated for this report, using Equation 5 of the ICRP Handbook[2].

d) For Case 4 dealing with inhalation of insoluble radioactive material and the lung as the critical body organ, use Table 5 of the ICRP Handbook[2], column 5, second value in parenthesis.

e) For Case 5 dealing with inhalation of insoluble radioactive material, in which case a portion of the GI tract is the critical body organ, use Table 5 of the ICRP Handbook[2], column 5, first value in parenthesis, for the upper and lower large intestines, each of which is assumed to have an effective diameter X = 5 cm.

Use Table 5 of the ICRP Handbook[2], column 5, second value in parenthesis for small intestine, which is assumed to have a value of X = 30 cm.

The values of Σ(bE)(RBE)N have not been calculated for the stomach with an assumed value of X = 10 cm. Therefore, they are calculated for this report, using Equation (5) of the ICRP Handbook[2].

(5) Coefficients of elimination and decay and half-lives

λ_r = coefficient of radioactive decay

λ_b = coefficient of biological elimination

$\lambda = \lambda_r + \lambda_b$ = effective coefficient

T_r = radioactive half-life

T_b = biological half-life

T = effective half-life

$$T = \frac{T_b T_r}{T_b + T_r}$$

The half-lives used are taken from the ICRP Handbook[2] except where more recent measurements are available; the values of T_r are given in column 3 of Table 5; T_b for the soluble radioactive material is given in column 13 of Table 4; and T is given in column 6 of Table 5. For the insoluble radioactive material, T_b is taken as 120 days, both for the lungs and for the tissue in a wound. For the case where the GI tract is the critical organ, T_b is calculated from the values of f_1 (see Appendix) in which f_1, the fraction going from the GI tract to the blood, is given in column 5, Table 4, of the ICRP Handbook[2].

(6) Fraction f retained in the critical body organ

The value of f for inhalation of soluble radioactive material is the same as given in the ICRP Handbook[2], Table 4, column 12 for the body organs listed in column 9. For inhalation of insoluble material f = 0.125 when the

lung is the critical organ, and f = 0.625 when the GI tract is the critical organ. The value of f for soluble radioactive material taken into the body as a result of a puncture wound is the same as that given for f_2 in column 15 of Table 4 of the ICRP Handbook[2]; since f_2 is the fraction going from the blood to the critical organ, this is equivalent to assuming all the soluble radioactive material injected into the body in a wound is taken up in the blood. In the case of insoluble radioactive material taken into the body as a result of a puncture wound, f is set equal to 1.

CALCULATIONS AND RESULTS

The relative hazard of the various radionuclides is based on five different criteria as follows:

Case (1). The inhalation of soluble radioactive material. In this case the critical body organ is one of the following: total body, muscle, fat, bone, blood, skin, lover, kidneys, spleen, or thyroid.

Case (2). The injection of soluble material into the body by way of a puncture wound. This case is similar to Case (1) except for the mode of entry into the body, and it is assumed the fraction, f_2, of the radioactive material arrives at the critical body organ immediately after the injection.

Case (3). The injection of insoluble radioactive material by way of a puncture wound. It is assumed that f = 1, and that all of the radioactive material remains in a localized mass of tissue of 10^{-3} grams at the site of the wound.

Case (4). The inhalation of insoluble radioactive material with the lung as the critical organ.

Case (5). The inhalation of insoluble radioactive material where some portion of the GI tract is the critical body tissue. The portions of the GI tract considered are the stomach, small intestine, upper large intestine, and lower large intestine. It is assumed some of the material is eliminated uniformly in the passage of the radioactive material through the small intestine and that radioactive daughter products--where present--contribute to the absorbed dose after they are produced along the GI tract.

The equations used in each of the above five cases are given in the next section of this report, and the derivations are given in the Appendix. Tables I, II, III, IV, and V of this report summarize the data for cases (1), (2), (3), (4), and (5), respectively, and give the maximum permissible intake (MPI) in μc that will deliver the specified dose to the indicated critical body organ. In Table IV the lung is the critical organ; in Table III the wound site is the critical tissue; and in Table V the portion of the GI tract resulting in the smallest (MPI) value is the critical organ. In the case of the GI tract (Table V) the calculations are made only on the basis of a permissible dose of 0.3 rem delivered in one week, since the total time in the GI tract is 31 hours. The lowest value of MPI in each case is given also in these Tables in mg in order to indicate the small amounts of radioactive material on a mass basis that corresponds to the limiting MPI value. It is apparent that in many cases this quantity is so small that it could be inhaled on a single dust particle or could be injected unnoticed

into the body as the result of a puncture wound. It is of interest to observe that, in spite of the low values of MPI in μc for natural thorium and natural uranium, the mg values are very large relative to the mg values for radionuclides such as Ra^{226}, and $Sr^{90} + Y^{90}$. This suggests that the radiation hazard may be proportional to the product of the probability of inhaling or injecting a given mass of the radioactive material and of the inverse of the minimum MPI value. Drinker and Hatch[7] have indicated that the average city and industrial air has a dust loading of from about 10^{-4} to 10^{-3} grams per cubic meter. This corresponds to an inhalation of 1 to 10 mg of dust in 8 hours. Therefore, in case of an accident with radioactive material it is not likely one would inhale more than 10 mg in an 8-hour period. There were 52,259 domestic shipments of radioactive material from our Laboratory[8] (ORNL) in 1954, and the average activity per shipment was 100 mc. These figures are exclusive of Co^{60}, which in many cases was shipped as large solid sources to be used as radiation therapy units. Therefore, for this comparison of radiation hazards, it is assumed that the amount involved in the accident is 100 mc in each case. Values of mg/100 mc are given in column 5 of Table V for convenient reference. The relative hazard in case of a spill or accident with one of these shipments of 100 mc of radioactive material is given by the equation,

$$H = \frac{10}{(MPI)(mg/100\ mc)} \qquad (1)$$

In this equation, 10/(mg/100 mc) is the probability of inhalation of 10 mg of radioactive material. This term can have values ≤ 1 in Equation (1), but when 10/(mg/100 mc) becomes > 1, it is assumed all the radioactive material can be inhaled in 8 hours, and in this case the hazard is given by H = 1/(MPI). The MPI to be used in Equation (1) is the smallest value given for the radioisotope in each table. In the case of a contaminated wound, the term, 10/(mg/100 mc), in Equation (1) is reduced to 1/(mg/100 mc) and this has a maximum value of 1. The values of H in Tables II and III relate to the probability of getting radioactive contamination of 1 mg or less into a wound.

It is apparent that there are other factors which may affect the relative hazard in case of an accidental spill of radioactive material. One of the most important of these factors is the form—physical and chemical—of the material at the time of the accident. Space will not permit an evaluation of all these factors, but Table VI, prepared by G. R. Patterson[9], gives information on the compounds shipped from our Laboratory (ORNL), the specific activity, the physical form, and an estimate of the probable fraction that would be available for intake by inhalation in case of an accident. These data and similar information for other chemical and physical forms and isotopic dilutions can be used to modify the basic data given for the single unadulterated radioisotopes in Tables I, II, III, IV, and V. Table VII is a summary of the 20 more dangerous radionuclides listed in the order of decreasing hazard.

Equations Used in the Calculations: (See Appendix for details of derivation and section on nomenclature for definition)

Case 1. Table I:

$$(MPI) = \frac{2.12 \times 10^{-3}\ D_m}{\pi r^2 (hL)(NHE)\Sigma \left[T_r(1 - e^{-0.231/T_r}) + T_b e^{-0.693\ t_2/T}(1 - e^{-0.231/T_b})\right]} \quad (2)$$

Case 2. Table II:

$$(MPI) = \frac{1.35 \times 10^{-2}\ D_m}{f_2' \pi r^2 (hL)(NHE)\Sigma \left[1 - e^{-0.693\ t_2/T}\right]} \quad (3)$$

Case 3. Table III:

$$(MPI) = \frac{1.35 \times 10^{-5}\ D}{\pi r^2 (hL)(NHE)\Sigma \left[1 - e^{-0.693\ t_2/T}\right]} \quad (4)$$

Case 4. Table IV:

$$(MPI) = \frac{.25\ D}{\pi r^2 (hL)(NHE)\Sigma \left[T_r(1 - e^{-0.231/T_r}) - 0.231\ e^{-0.693\ t_2/T}\right]} \quad (5)$$

Case 5. Table V:

$$(MPI)_{GI} = \text{Min}\left[(MPI)_{stomach},\ (MPI)_{intestine}\right]. \quad (6)$$

The solution of this equation for the GI tract is rather involved (See Appendix), and numerical values were found by use of the CEEL digital computer.

CONCLUSIONS

In case a person receives a single exposure to relatively insoluble radioactive material, the localized dose is likely to be much greater if the material contaminates an open wound than if it enters the body by ingestion or inhalation. This may lend support to the common medical practice of excising contaminated tissue from such a wound. Table VII, which is a comparative summary of the 20 more dangerous radionuclides, indicates that many of the radionuclides are in the very hazardous group regardless of whether they are inhaled or injected; whether they are soluble or insoluble; and whether the wound site, the lung, the GI tract or some other organ is the critical body organ. For example, Ac^{227}, At^{211}, Po^{210}, Am^{241}, Pu^{239}, and $Sr^{90} + Y^{90}$ are generally among the more hazardous isotopes, the first four being among the 12 more hazardous in every case. For inhalation, the lung or GI tract is usually the critical body organ. In case of accident the ingestion hazard is considered to be negligible compared with the inhalation or injection hazard. The absorbed dose from each of the radionuclides is calculated by means of the digital computer at 31 points along the GI tract. The lower large intestine is usually the critical portion of the GI tract but, where the effective half-life is short, other portions, i.e., stomach, small intestine, and upper large intestine, may become the critical tissue. Five of the radionuclides—$Sr^{90}+Y^{90}$, Sm^{151}, Pu^{239}, Ra^{226}, and Th^{232}—have very long biological half-lives so that the limiting restriction leading to the smallest MPI is the requirement that the integrated dose as a result of a single body intake must not exceed 150 rem in a lifetime (during the following 70 years). For the rest of the radionuclides, the smallest MPI is obtained when the integrated dose is limited to 0.3 rem during the week following the exposure.

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TABLE I

SINGLE EXPOSURE VALUES FOR INHALATION OF SOLUBLE RADIOACTIVE MATERIAL WHEN BODY ORGANS OTHER THAN THE GI TRACT OR LUNGS ARE THE CRITICAL BODY ORGANS

(1) Z	(2) Isotope	(3) Critical Organ	(4) Fraction Deposited in Critical Organ f	(5) MPI[c] or μc Inhaled in 8 Hours that will Present a Dose of: 0.3 rem in 1 wk	(6) 15.7 rem in 1 yr	(7) 150 rem in 70 yrs	(8) Smallest Values in Columns 5, 6 and 7 in mg	(9) Relative Hazard[a,b] H
1	H^3 (HTO or H_2^3O)	T. body	0.75	1.5×10^4	1.7×10^5	1.7×10^6	1.6×10^{-3}	6.6×10^{-5}
4	Be^7	Bone	9.0×10^{-2}	7.7×10^3	4.0×10^4	3.7×10^5	2.2×10^{-5}	1.3×10^{-4}
6	$C^{14}(CO_2)$	Fat	0.36	4.7×10^2	3.2×10^3	3.0×10^4	0.10	9.6×10^{-4}
9	F^{18}	Bone	7.5×10^{-2}	1.3×10^4	6.7×10^5	6.3×10^6	1.4×10^{-7}	7.8×10^{-5}
11	Na^{24}	T. body	0.73	2.8×10^2	1.5×10^4	1.4×10^5	3.3×10^{-8}	3.6×10^{-3}
15	P^{32}	Bone	0.2	53	8.0×10^2	7.7×10^3	1.9×10^{-7}	1.9×10^{-2}
16	S^{35}	Skin	7.4×10^{-2}	4.7×10^2	5.7×10^3	5.7×10^4	1.1×10^{-5}	2.1×10^{-3}
17	Cl^{36}	T. body	0.73	3.7×10^2	4.0×10^3	4.0×10^4	15	6.6×10^{-6}
19	K^{42}	Muscle	0.53	3.3×10^2	1.8×10^4	1.7×10^4	5.7×10^{-8}	3×10^{-3}
20	Ca^{45}	Bone	0.41	33	67	5.0×10^2	2.0×10^{-6}	3×10^{-2}
21	Sc^{46}	Spleen Liver	7.5×10^{-3} 0.12	40 29	6.7×10^2 4.7×10^2	6.3×10^3 4.3×10^3	8.7×10^{-7}	3.3×10^{-2}
21	Sc^{47}	Spleen Liver	7.5×10^{-3} 0.12	1.8×10^2 1.2×10^2	7.3×10^3 5.3×10^3	7.0×10^4 5.0×10^4	1.5×10^{-7}	8.1×10^{-3}
21	Sc^{48}	Spleen Liver	7.5×10^{-3} 0.12	87 50	4.3×10^3 2.5×10^3	4.3×10^4 2.4×10^4	3.3×10^{-8}	2.0×10^{-2}
23	V^{48}	Bone	0.025	2.7×10^2	4.7×10^3	4.3×10^4	1.6×10^{-6}	3.9×10^{-3}
24	Cr^{51}	Kidneys	4×10^{-3}	10^4	10^5	10^6	1.1×10^{-4}	9.9×10^{-5}
25	Mn^{56}	Kidneys Liver	2.2×10^{-2} 9×10^{-2}	1.2×10^3 1.6×10^3	6.0×10^4 8.3×10^4	6.0×10^5 8.0×10^5	5.3×10^{-8}	8.7×10^{-4}
26	Fe^{55}	Blood	0.65	1.2×10^3	5.0×10^3	4.3×10^4	5.7×10^{-4}	8.4×10^{-4}
26	Fe^{59}	Blood	0.65	14	1.2×10^2	1.2×10^3	2.8×10^{-7}	7.2×10^{-2}
27	Co^{60}	Liver	7×10^{-3}	3.7×10^2	8.7×10^3	8.3×10^4	3.2×10^{-4}	2.7×10^{-3}

(a) The larger the number in this column the greater the hazard.
(b) Values of H in this column correspond to the smallest value in columns 5, 6 or 7.
(c) The MPI is the μc present initially in the volume of air to be breathed during the succeeding 8 hours and which then results in the indicated dose.

TABLE I
(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) ag	(9) E
28	Ni^{59}	Liver	7×10^{-3}	5.7×10^{3}	1.3×10^{5}	1.2×10^{6}	73	1.4×10^{-6}
29	Cu^{64}	Liver	0.13	8.3×10^{2}	4.3×10^{4}	4.0×10^{5}	2.2×10^{-7}	1.2×10^{-3}
30	Zn^{65}	Bone	4.5×10^{-2}	1.5×10^{3}	1.6×10^{4}	1.6×10^{5}	1.8×10^{-4}	6.6×10^{-4}
31	Ga^{72}	Bone	0.1	2.2×10^{2}	1.2×10^{4}	1.1×10^{5}	7.3×10^{-8}	4.5×10^{-3}
32	Ge^{71}	Kidneys	5×10^{-3}	9.0×10^{3}	3.3×10^{5}	3.2×10^{6}	5.7×10^{-5}	1.1×10^{-4}
33	As^{76}	Kidneys	2.7×10^{-3}	4.3×10^{2}	2.2×10^{4}	2.1×10^{5}	2.8×10^{-7}	2.3×10^{-3}
37	Rb^{86}	Muscle	0.33	1.4×10^{2}	3.3×10^{3}	3.2×10^{4}	1.8×10^{-6}	6.9×10^{-3}
38	Sr^{89}	Bone	0.22	10	47	4.3×10^{2}	3.7×10^{-7}	9.9×10^{-2}
38	Sr^{90} + Y^{90}	Bone	0.22	5.3	5.7	2	2.5×10^{-5}	0.20
39	Y^{91}	Bone	0.14	36	73	7.0×10^{2}	6.3×10^{-7}	6.3×10^{-2}
40	Zr^{95} + Nb^{95}	Bone	5.8×10^{-2}	1.1×10^{2}	5.3×10^{2}	5.3×10^{3}	5.0×10^{-4}	9.0×10^{-3}
41	Nb^{95}	Bone	0.12	1.7×10^{2}	1.8×10^{3}	1.7×10^{4}	4.3×10^{-6}	6.0×10^{-3}
42	Mo^{99}	Bone	2×10^{-4}	9.3×10^{4}	4.0×10^{6}	4.0×10^{7}	2.0×10^{-4}	1.1×10^{-5}
43	Tc^{96}	Kidneys	3×10^{-3}	4.7×10^{2}	2.1×10^{4}	2.0×10^{5}	1.4×10^{-6}	2.1×10^{-3}
44	Ru^{106} + Rh^{106}	Kidneys	10^{-2}	20	8.4×10^{2}	2.3×10^{3}	6.0×10^{-6}	4.8×10^{-2}
45	Rh^{105}	Kidneys	2×10^{-2}	1.4×10^{2}	7.0×10^{3}	6.7×10^{4}	1.7×10^{-7}	7.2×10^{-3}
46	Pd^{103} + $^{103}_{a}$	Kidneys	4×10^{-2}	1.4×10^{2}	5.0×10^{3}	4.7×10^{4}	1.9×10^{-6}	6.9×10^{-3}
47	Ag^{105}	Liver	2×10^{-3}	2.0×10^{3}	8.7×10^{4}	8.3×10^{5}	7.3×10^{-5}	4.8×10^{-4}
47	Ag^{111}	Liver	2×10^{-3}	5.0×10^{3}	2.4×10^{5}	2.3×10^{6}	3.2×10^{-5}	2.0×10^{-4}
48	Cd^{109} + $^{109}_{a}$	Liver	0.19	2.0×10^{2}	6.0×10^{2}	5.7×10^{3}	7.7×10^{-5}	5.1×10^{-3}
50	Sn^{113} + In^{113}	Bone	7.6×10^{-2}	9.3×10^{2}	5.0×10^{3}	5.0×10^{4}	9.0×10^{-5}	1.1×10^{-3}
52	Te^{127}	Kidneys	2×10^{-2}	53	8.7×10^{2}	8.3×10^{3}	6.0×10^{-6}	1.9×10^{-2}
52	Te^{129}	Kidneys	2×10^{-2}	18	3.7×10^{2}	3.3×10^{3}	6.0×10^{-7}	5.4×10^{-2}
53	I^{131}	Thyroid	0.15	0.70	17	1.7×10^{2}	5.7×10^{-9}	1.4

TABLE I
(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) mg	(9) H
55	Cs^{137} + Ba^{137s}	Muscle	0.36	1.4×10^{2}	1.8×10^{3}	1.7×10^{4}	1.8×10^{-3}	6.9×10^{-3}
56	Ba^{140} + La^{140}	Bone	0.2	8.7	1.5×10^{2}	1.4×10^{3}	1.2×10^{-7}	0.11
57	La^{140}	Bone	0.1	70	3.3×10^{3}	3.3×10^{4}	1.2×10^{-7}	1.4×10^{-2}
58	Ce^{144} + Pr^{144}	Bone	0.1	9.3	17	1.2×10^{2}	3.0×10^{-6}	0.11
59	Pr^{143}	Bone	6.3×10^{-2}	73	1.4×10^{3}	1.3×10^{4}	1.1×10^{-6}	1.4×10^{-2}
61	Pm^{147}	Bone	9×10^{-2}	2.0×10^{2}	5.7×10^{2}	5.3×10^{3}	2.1×10^{-4}	5.1×10^{-3}
62	Sm^{151}	Bone	5×10^{-2}	1.1×10^{3}	1.2×10^{3}	2.4×10^{2}	10^{-2}	4.2×10^{-3}
63	Eu^{154}	Bone	9×10^{-2}	57	60	1.2×10^{2}	4.0×10^{-4}	1.8×10^{-2}
67	Ho^{166}	Bone	7×10^{-2}	1.3×10^{2}	6.7×10^{3}	6.3×10^{4}	1.9×10^{-7}	7.8×10^{-3}
69	Tm^{170}	Bone	0.18	21	90	8.3×10^{2}	3.7×10^{-6}	4.8×10^{-2}
71	Lu^{177}	Bone	7.5×10^{-2}	2.4×10^{2}	9.7×10^{3}	9.3×10^{4}	2.2×10^{-6}	4.2×10^{-3}
73	Ta^{182}	Liver	7.5×10^{-2}	47	1.8×10^{2}	1.7×10^{3}	7.0×10^{-6}	2.1×10^{-2}
74	W^{181}	Bone	2.4×10^{-2}	9.3×10^{3}	3.3×10^{4}	3.3×10^{5}	1.8×10^{-3}	1.1×10^{-4}
75	Re^{183}	Thyroid Skin	1.3×10^{-3} 0.12	1.4×10^{3} 7.3×10^{3}	7.3×10^{4} 2.4×10^{5}	7.0×10^{5} 2.3×10^{6}	2.3×10^{-4}	7.2×10^{-4}
77	Ir^{190}	Kidneys Spleen	1.7×10^{-2} 6×10^{-3}	2.9×10^{2} 4.0×10^{2}	7.3×10^{3} 7.7×10^{3}	7.0×10^{4} 7.3×10^{4}	4.7×10^{-6}	3.3×10^{-3}
77	Ir^{192}	Kidneys Spleen	2×10^{-2} 6×10^{-3}	31 47	4.0×10^{2} 2.5×10^{2}	3.7×10^{3} 2.3×10^{3}	3.3×10^{-6}	3.3×10^{-2}
78	Pt^{191}	Kidneys	3.3×10^{-2}	43	1.8×10^{3}	1.7×10^{4}	1.9×10^{-7}	2.3×10^{-2}
78	Pt^{193}	Kidneys	3.3×10^{-2}	40	1.4×10^{3}	1.4×10^{4}	2.5×10^{-7}	2.5×10^{-2}
79	Au^{196}	Liver Kidneys	0.25 7.2×10^{-2}	53 43	1.7×10^{3} 1.4×10^{3}	1.7×10^{4} 1.3×10^{4}	3.7×10^{-7}	2.3×10^{-2}
79	Au^{198}	Liver Kidneys	0.25 7.2×10^{-2}	31 20	1.4×10^{3} 9.0×10^{2}	1.3×10^{4} 8.7×10^{3}	8.3×10^{-8}	4.8×10^{-2}
79	Au^{199}	Liver Kidneys	0.25 7.2×10^{-2}	73 53	3.0×10^{3} 2.1×10^{3}	2.9×10^{4} 2.0×10^{4}	2.7×10^{-7}	1.9×10^{-2}

TABLE I

(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) mg	(9) H
81	Tl^{200}	Muscle	0.26	4.0×10^{2}	2.1×10^{4}	2.0×10^{5}	7.0×10^{-7}	2.5×10^{-3}
81	Tl^{201}	Muscle	0.26	1.4×10^{3}	6.0×10^{4}	6.0×10^{5}	6.3×10^{-6}	7.2×10^{-4}
81	Tl^{202}	Muscle	0.26	6.7×10^{2}	1.7×10^{4}	1.6×10^{5}	1.2×10^{-5}	1.5×10^{-3}
81	Tl^{204}	Muscle	0.26	4.7×10^{2}	6.0×10^{3}	5.7×10^{4}	1.1×10^{-3}	2.1×10^{-3}
82	Pb^{203}	Bone	9.8×10^{-2}	1.3×10^{3}	6.3×10^{4}	6.0×10^{5}	4.3×10^{-6}	7.5×10^{-4}
82	Pb^{210} + dr	Bone	9.8×10^{-2}	0.21	0.26	0.80	2.7×10^{-6}	4.8
84	Po^{210}	Spleen	4×10^{-3}	0.60	3.7	33	1.3×10^{-7}	1.7
85	At^{211}	Thyroid	0.05	0.10	5.3	53	5.0×10^{-11}	9.6
88	Ra^{226} + 55% dr	Bone	2.6×10^{-2}	1.4	1.4	0.32	3.2×10^{-4}	0.30
89	Ac^{227} + dr	Bone	7.5×10^{-2}	4.7×10^{-3}	5.3×10^{-2}	0.11	6.3×10^{-8}	2.1×10^{2}
90	Th-nat	Bone	0.2	1.6×10^{-2}	1.5×10^{-2}	2.6×10^{-3}	23	4.2×10^{-6}
90	Th^{234} + Pa^{234}	Bone	0.2	7.7	73	7.0×10^{2}	3.3×10^{-7}	0.13
92	U-nat	Kidneys	8×10^{-2}	3.7×10^{-2}	0.28	2.7	1.1×10^{2}	9.3×10^{-7}
92	U^{233}	Bone	5×10^{-2}	0.43	0.70	3.7	4.7×10^{-2}	2.1×10^{-3}
94	Pu^{239}	Bone	0.18	0.13	0.12	2.0×10^{-2}	3.2×10^{-4}	0.30
95	Am^{241}	Bone	6.3×10^{-2}	0.33	0.37	0.90	1.1×10^{-4}	0.90
96	Cm^{242}	Bone	6.3×10^{-2}	0.29	0.67	5.7	8.7×10^{-8}	3.3

(s) The daughter products in these cases are isomers in an excited state.

TABLE II

SINGLE EXPOSURE VALUES FOR INJECTION (OR PUNCTURE WOUNDS)
WHEN SOLUBLE RADIOACTIVE MATERIALS ARE TAKEN INTO THE BODY

(1) Z	(2) Isotope	(3) Critical Organ	(4) Fraction Going from Blood to Critical Organ f_2	(5) MPI or μc Injected that Will Result in a Dose of: 0.3 rem in 1 wk	(6) 15.7 rem in 1 yr	(7) 150 rem in 70 yrs	(8) Smallest Values in Columns 5, 6 or 7 in mg	(9) Relative Hazard(a,b) H
1	H^3 (HTO or H_2^3O)	T. body	1.0	1.1×10^4	1.3×10^5	1.2×10^6	1.1×10^{-3}	9.1×10^{-5}
4	Be^7	Bone	0.35	2.0×10^3	10^4	9.6×10^4	5.7×10^{-6}	5.0×10^{-4}
6	C^{14} (CO_2)	Fat	0.5	3.4×10^2	2.3×10^3	2.2×10^4	7.5×10^{-8}	1.3×10^{-4}
9	F^{18}	Bone	0.1	3.0×10^3	1.6×10^5	1.5×10^6	3.2×10^{-8}	3.3×10^{-4}
11	Na^{24}	T. body	1.0	1.7×10^2	9.0×10^3	8.6×10^4	2.0×10^{-8}	5.9×10^{-3}
15	P^{32}	Bone	0.3	34	5.2×10^2	5.0×10^3	1.2×10^{-7}	2.9×10^{-2}
16	S^{35}	Skin	0.14	2.5×10^2	3.0×10^3	2.9×10^4	5.8×10^{-6}	4.0×10^{-3}
17	Cl^{36}	T. body	1.0	2.6×10^2	3.0×10^3	2.9×10^4	11	9.4×10^{-7}
19	K^{42}	Muscle	0.75	1.9×10^2	10^4	9.9×10^4	3.2×10^{-8}	5.3×10^{-3}
20	Ca^{45}	Bone	0.58	24	46	3.5×10^2	1.3×10^{-6}	4.2×10^{-2}
21	Sc^{46}	Spleen Liver	3×10^{-2} 0.6	10 57	1.6×10^2 92	1.6×10^3 8.8×10^2	3.0×10^{-7}	0.10
21	Sc^{47}	Spleen Liver	3×10^{-2} 0.6	31 24	1.4×10^3 10^3	1.3×10^4 9.8×10^3	2.9×10^{-8}	4.2×10^{-2}
21	Sc^{48}	Spleen Liver	3×10^{-2} 0.6	20 9.4	10^3 4.7×10^2	9.7×10^3 4.5×10^3	6.3×10^{-9}	0.11
23	V^{48}	Bone	0.1	64	1.1×10^3	1.1×10^4	3.7×10^{-7}	1.6×10^{-2}
24	Cr^{51}	Kidneys	1.4×10^{-2}	2.8×10^3	2.9×10^4	2.8×10^5	3.0×10^{-5}	3.6×10^{-4}
25	Mn^{56}	Kidneys Liver	8×10^{-2} 0.16	1.3×10^2 3.7×10^2	6.9×10^3 1.9×10^4	6.6×10^4 1.8×10^5	6.0×10^{-9}	7.7×10^{-3}
26	Fe^{55}	Blood	1.0	7.8×10^2	3.2×10^3	3.0×10^4	3.6×10^{-4}	1.3×10^{-3}

(a) The larger the number in this column the greater the hazard.
(b) Values of H in this column correspond to the smallest values in columns 5, 6, or 7.

TABLE II

(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f_2	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) mg	(9) H
26	Fe^{59}	Blood	1.0	9.1	79	7.5×10^{2}	1.8×10^{-7}	0.11
27	Co^{60}	Liver	2×10^{-2}	1.3×10^{2}	3.0×10^{3}	2.8×10^{4}	1.1×10^{-4}	7.7×10^{-3}
28	Ni^{59}	Liver	2×10^{-2}	1.9×10^{3}	4.5×10^{4}	4.3×10^{5}	25	4.0×10^{-7}
29	Cu^{64}	Liver	0.33	2.6×10^{2}	1.4×10^{4}	1.3×10^{5}	6.8×10^{-8}	3.8×10^{-3}
30	Zn^{65}	Bone	0.15	4.5×10^{2}	4.8×10^{3}	4.6×10^{4}	5.4×10^{-5}	2.2×10^{-3}
31	Ga^{72}	Bone	0.4	46	2.4×10^{3}	2.3×10^{4}	1.5×10^{-8}	2.2×10^{-2}
32	Ge^{71}	Kidneys	2×10^{-2}	2.2×10^{3}	8.2×10^{4}	7.8×10^{5}	1.4×10^{-5}	4.5×10^{-4}
33	As^{76}	Kidneys	1×10^{-2}	10^{2}	5.3×10^{3}	5.1×10^{4}	6.4×10^{-8}	10^{-2}
37	Rb^{86}	Muscle	0.44	10^{2}	2.5×10^{3}	2.4×10^{4}	1.3×10^{-6}	10^{-2}
38	Sr^{89}	Bone	0.4	5.5	26	2.4×10^{2}	2.0×10^{-7}	0.18
38	Sr^{90} + Y^{90}	Bone	0.4	2.9	3.0	2.7	1.3×10^{-5}	0.34
39	Y^{91}	Bone	0.55	4.0	19	1.8×10^{2}	1.6×10^{-7}	0.25
40	Zr^{93} Nb^{95} +	Bone	0.23	27	1.4×10^{2}	1.3×10^{3}	1.3×10^{-5}	3.7×10^{-2}
41	Nb^{95}	Bone	0.25	79	8.6×10^{2}	8.2×10^{3}	2.0×10^{-6}	1.3×10^{-2}
42	Mo^{99}	Bone	3×10^{-4}	5.9×10^{4}	2.6×10^{6}	2.4×10^{7}	1.3×10^{-4}	1.7×10^{-5}
43	Tc^{96}	Kidneys	5×10^{-3}	2.6×10^{2}	1.2×10^{4}	1.2×10^{5}	8.0×10^{-7}	3.8×10^{-3}
44	Ru^{106} Rh^{106} +	Kidneys	4×10^{-2}	5.1	60	5.7×10^{2}	1.5×10^{-6}	0.2
45	Rh^{105}	Kidneys	5×10^{-2}	51	2.6×10^{3}	2.4×10^{4}	6.2×10^{-8}	2.0×10^{-2}
46	Pd^{103} + Rh^{103}s	Kidneys	0.1	56	2.0×10^{3}	1.9×10^{4}	7.5×10^{-7}	1.8×10^{-2}
47	Ag^{105}	Liver	6×10^{-3}	6.8×10^{2}	2.9×10^{4}	2.8×10^{5}	2.4×10^{-5}	1.5×10^{-3}
47	Ag^{111}	Liver	6×10^{-3}	1.6×10^{3}	7.7×10^{4}	7.4×10^{5}	10^{-5}	6.3×10^{-4}
48	Cd^{109} + Ag^{109}s	Liver	0.75	49	1.5×10^{2}	1.4×10^{3}	1.9×10^{-5}	2.0×10^{-2}
50	Sn^{113}	Bone	0.3	2.4×10^{2}	1.3×10^{3}	1.2×10^{4}	2.3×10^{-5}	4.2×10^{-3}

TABLE II

(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f_2'	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) mg	(9) H
52	Te^{127}	Kidneys	6×10^{-2}	18	2.9×10^{2}	2.8×10^{3}	2.0×10^{-6}	5.6×10^{-2}
52	Te^{129}	Kidneys	6×10^{-2}	5.9	1.2×10^{2}	1.1×10^{3}	1.9×10^{-7}	0.17
53	I^{131}	Thyroid	0.2	0.52	13	1.2×10^{2}	4.1×10^{-9}	1.9
55	$Cs^{137} + Ba^{137s}$	Muscle	0.48	1.1×10^{2}	1.4×10^{3}	1.3×10^{4}	1.4×10^{-3}	7.3×10^{-3}
56	$Ba^{140} + La^{140}$	Bone	0.7	2.4	41	3.9×10^{2}	3.3×10^{-8}	0.42
57	La^{140}	Bone	0.4	16	8.0×10^{2}	7.6×10^{3}	2.8×10^{-8}	6.3×10^{-2}
58	$Ce^{144} + Pr^{144}$	Bone	0.4	2.3	4.3	31	7.3×10^{-7}	0.43
59	Pr^{143}	Bone	0.25	18	3.4×10^{2}	3.2×10^{3}	2.7×10^{-7}	5.6×10^{-2}
61	Pm^{147}	Bone	0.35	50	1.5×10^{2}	1.3×10^{3}	5.3×10^{-5}	2.0×10^{-2}
62	Sm^{151}	Bone	0.2	3.0×10^{2}	2.9×10^{2}	60	2.5×10^{-3}	3.9×10^{-3}
63	Eu^{154}	Bone	0.35	14	16	31	9.5×10^{-5}	7.1×10^{-2}
67	Ho^{166}	Bone	0.22	37	1.9×10^{3}	1.8×10^{4}	5.3×10^{-8}	2.7×10^{-2}
69	Tm^{170}	Bone	0.7	5.4	23	2.1×10^{2}	8.9×10^{-7}	0.19
71	Lu^{177}	Bone	0.3	58	2.4×10^{3}	2.3×10^{4}	5.3×10^{-7}	1.7×10^{-2}
73	Ta^{182}	Liver	0.3	11	46	4.3×10^{2}	1.7×10^{-6}	9.1×10^{-2}
74	W^{181}	Bone	8×10^{-2}	2.1×10^{3}	10^{4}	10^{5}	4.0×10^{-4}	4.8×10^{-4}
75	Re^{183}	Thyroid Skin	2.5×10^{-3} 0.8	7.2×10^{2} 1.1×10^{3}	3.8×10^{4} 3.5×10^{4}	3.6×10^{5} 3.4×10^{5}	1.2×10^{-4}	1.4×10^{-3}
77	Ir^{190}	Kidneys Spleen	5×10^{-2} 8×10^{-2}	98 28	2.5×10^{3} 5.7×10^{2}	2.4×10^{4} 5.4×10^{3}	4.3×10^{-7}	3.6×10^{-2}

TABLE II

(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f_2'	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) mg	(9) H
77	Ir^{192}	Kidneys Spleen	5×10^{-2} 8×10^{-2}	12 3.6	1.5×10^{2} 18	1.5×10^{3} 1.8×10^{2}	3.9×10^{-7}	0.28
78	Pt^{191}	Kidneys	0.11	12	5.1×10^{2}	4.9×10^{3}	5.2×10^{-8}	8.3×10^{-2}
78	Pt^{193}	Kidneys	0.11	11	4.1×10^{2}	3.9×10^{3}	6.9×10^{-8}	9.1×10^{-2}
79	Au^{196}	Liver Kidneys	0.98 0.24	13 13	4.3×10^{2} 4.1×10^{2}	4.1×10^{3} 3.9×10^{3}	1.1×10^{-7}	7.7×10^{-2}
79	Au^{198}	Liver Kidneys	0.98 0.24	7.4 5.8	3.3×10^{2} 2.5×10^{2}	3.1×10^{3} 2.4×10^{3}	2.3×10^{-8}	0.17
79	Au^{199}	Liver Kidneys	0.98 0.24	18 15	7.4×10^{2} 6.1×10^{2}	7.1×10^{3} 5.8×10^{3}	7.5×10^{-8}	6.7×10^{-2}
81	Tl^{200}	Muscle	6×10^{-2}	1.6×10^{3}	8.1×10^{4}	7.7×10^{5}	2.7×10^{-6}	6.3×10^{-4}
81	Tl^{201}	Muscle	6×10^{-2}	5.8×10^{3}	2.5×10^{5}	2.4×10^{6}	2.7×10^{-5}	1.7×10^{-4}
81	Tl^{202}	Muscle	6×10^{-2}	2.8×10^{3}	7.2×10^{4}	6.9×10^{5}	5.1×10^{-5}	3.6×10^{-4}
81	Tl^{204}	Muscle	6×10^{-2}	1.9×10^{3}	2.5×10^{4}	2.4×10^{5}	4.4×10^{-3}	5.3×10^{-4}
82	Pb^{203}	Bone	0.3	4.1×10^{2}	1.9×10^{4}	1.8×10^{5}	1.4×10^{-6}	2.4×10^{-3}
82	Pb^{210}	Bone	0.3	7.1×10^{-2}	8.5×10^{-2}	0.25	9.1×10^{-7}	11
84	Po^{210}	Spleen	2×10^{-2}	0.12	0.72	6.9	2.7×10^{-8}	8.3
85	At^{211}	Thyroid	7×10^{-2}	5.3×10^{-2}	2.8	26	2.6×10^{-11}	19
88	Ra^{226} + 55% dr	Bone	7.5×10^{-2}	0.49	0.49	0.11	1.1×10^{-4}	9.0×10^{-2}
89	Ac^{227} + dr	Bone	0.3	1.2×10^{-2}	1.3×10^{-2}	2.8×10^{-2}	1.7×10^{-7}	60
90	Th-nat	Bone	0.78	4.5×10^{-3}	4.0×10^{-3}	6.7×10^{-4}	5.9	1.7×10^{-6}
90	Th^{234} + Pa^{234}	Bone	0.78	1.9	18	1.8×10^{2}	8.1×10^{-8}	0.53
92	U-nat	Kidneys	0.33	8.7×10^{-3}	6.8×10^{-2}	0.65	26	3.9×10^{-7}
92	U^{233}	Bone	0.33	7.1×10^{-2}	0.11	0.57	7.4×10^{-3}	1.3×10^{-3}
94	Pu^{239}	Bone	0.7	3.5×10^{-2}	3.1×10^{-2}	5.2×10^{-3}	8.3×10^{-5}	0.12

TABLE II

(cont'd)

(1) Z	(2) Isotope	(3) Critical Organ	(4) f_2'	(5) MPI (μc) 0.3 rem in 1 wk	(6) MPI (μc) 15.7 rem in 1 yr	(7) MPI (μc) 150 rem in 70 yrs	(8) ag	(9) H
95	Am^{241}	Bone	0.25	8.4×10^{-2}	9.6×10^{-2}	0.23	2.8×10^{-5}	0.36
96	Cm^{242}	Bone	0.25	7.6×10^{-2}	0.17	0.14	2.3×10^{-8}	13

(s) The daughter products in these cases are isomers in an excited state.

TABLE III

SINGLE EXPOSURE VALUES FOR INJECTION (OR PUNCTURE WOUNDS) WHEN INSOLUBLE RADIOACTIVE MATERIAL IS DEPOSITED IN THE WOUND

(1)	Isotope	(2) MPI or μc injected that will result in a dose of: 0.3 rem in 1 wk	(3) MPI or μc injected that will result in a dose of: 15.7 rem in 1 yr	(4) MPI or μc injected that will result in a dose of: 150 rem in 70 yrs	(5) mg corresponding to smallest value in columns 2,3, or 4	(6) Relative Hazard H
1	H^3 (HTO or H_2^3O)	1.4×10^{-4}	3.3×10^{-4}	2.9×10^{-3}	1.4×10^{-11}	7.1×10^{3}
4	Be^7	8.1×10^{-4}	5.0×10^{-3}	5.0×10^{-2}	2.3×10^{-12}	1.2×10^{3}
6	C^{14} (CO_2)	1.6×10^{-5}	3.6×10^{-5}	3.2×10^{-4}	3.5×10^{-9}	2.9×10^{3}
9	F^{18}	2.2×10^{-4}	1.1×10^{-2}	0.11	2.3×10^{-15}	4.5×10^{3}
11	Na^{24}	9.9×10^{-6}	4.9×10^{-4}	4.9×10^{-3}	1.1×10^{-15}	10^{5}
15	P^{32}	1.5×10^{-6}	2.3×10^{-5}	2.3×10^{-4}	5.2×10^{-15}	6.7×10^{5}
16	S^{35}	1.6×10^{-5}	7.4×10^{-5}	7.4×10^{-4}	3.7×10^{-13}	6.3×10^{4}
17	Cl^{36}	3.3×10^{-6}	7.4×10^{-6}	6.5×10^{-5}	1.4×10^{-7}	71×10^{1}
19	K^{42}	5.6×10^{-6}	2.8×10^{-4}	2.8×10^{-3}	9.3×10^{-16}	1.8×10^{5}
20	Ca^{45}	10^{-5}	3.5×10^{-5}	3.4×10^{-4}	5.6×10^{-13}	10^{5}
21	Sc^{46}	6.3×10^{-6}	2.9×10^{-5}	2.9×10^{-4}	1.9×10^{-13}	1.6×10^{5}
21	Sc^{47}	7.5×10^{-6}	2.9×10^{-4}	2.9×10^{-3}	9.2×10^{-15}	1.3×10^{5}
21	Sc^{48}	10^{-5}	4.9×10^{-4}	4.9×10^{-3}	6.7×10^{-15}	10^{5}
23	V^{48}	6.6×10^{-6}	9.6×10^{-5}	9.6×10^{-4}	3.9×10^{-14}	1.5×10^{5}
24	Cr^{51}	4.6×10^{-4}	4.4×10^{-3}	4.4×10^{-2}	5.0×10^{-12}	2.2×10^{3}
25	Mn^{56}	4.4×10^{-5}	2.2×10^{-3}	2.2×10^{-2}	2.0×10^{-15}	2.3×10^{4}
26	Fe^{55}	1.4×10^{-4}	3.5×10^{-4}	3.1×10^{-3}	6.4×10^{-11}	7.1×10^{3}
26	Fe^{59}	7.5×10^{-6}	5.1×10^{-5}	5.1×10^{-4}	1.7×10^{-13}	1.3×10^{5}
27	Co^{60}	7.8×10^{-6}	1.8×10^{-5}	1.6×10^{-4}	6.8×10^{-12}	1.3×10^{5}
28	Ni^{59}	1.7×10^{-5}	3.8×10^{-5}	3.4×10^{-4}	2.2×10^{-7}	45×10^{1}

TABLE III

(cont'd)

(1)	Isotope	(2) 0.3 rem in 1 wk	(3) 15.7 rem in 1 yr	(4) 150 rem in 70 yrs	(5) (mg)	(6) H
29	Cu^{64}	7.5×10^{-5}	3.8×10^{-3}	3.8×10^{-2}	2.0×10^{-14}	1.3×10^{4}
30	Zn^{65}	6.6×10^{-5}	2.0×10^{-4}	1.9×10^{-3}	8.0×10^{-12}	1.5×10^{4}
31	Ga^{72}	1.5×10^{-5}	7.6×10^{-4}	7.6×10^{-3}	4.8×10^{-15}	6.7×10^{4}
32	Ge^{71}	1.1×10^{-4}	2.0×10^{-3}	2.0×10^{-2}	6.8×10^{-13}	9.1×10^{3}
33	As^{76}	3.6×10^{-6}	1.8×10^{-4}	1.8×10^{-3}	2.3×10^{-15}	2.8×10^{5}
37	Rb^{86}	1.6×10^{-6}	2.0×10^{-5}	2.0×10^{-4}	2.0×10^{-14}	6.3×10^{5}
38	Sr^{89}	1.6×10^{-6}	10^{-5}	9.9×10^{-5}	5.7×10^{-14}	6.3×10^{5}
38	Sr^{90}+Y^{90}	8.5×10^{-7}	1.9×10^{-6}	1.7×10^{-5}	4.3×10^{-12}	1.2×10^{6}
39	Y^{91}	1.6×10^{-6}	9.1×10^{-6}	9.1×10^{-5}	6.4×10^{-14}	6.3×10^{5}
40	Zr^{95}+Nb^{95}	4.9×10^{-6}	2.7×10^{-5}	2.7×10^{-4}	1.2×10^{-13}	2.0×10^{5}
41	Nb^{95}	1.9×10^{-5}	1.6×10^{-4}	1.6×10^{-3}	8.9×10^{-13}	5.3×10^{4}
42	Mo^{99}	1.4×10^{-5}	5.6×10^{-4}	5.6×10^{-3}	3.0×10^{-14}	7.1×10^{4}
43	Tc^{96}	5.5×10^{-5}	1.9×10^{-3}	1.9×10^{-2}	1.7×10^{-13}	1.8×10^{4}
44	Ru^{106}+Rh^{106}	6.3×10^{-7}	1.8×10^{-6}	1.7×10^{-5}	1.9×10^{-13}	1.6×10^{6}
45	Rh^{105}	10^{-5}	5.0×10^{-4}	5.0×10^{-3}	1.2×10^{-14}	10^{5}
46	Pd^{103}+Rh^{103m}	2.7×10^{-5}	3.8×10^{-4}	3.8×10^{-3}	3.6×10^{-13}	3.8×10^{4}
47	Ag^{105}	9.0×10^{-5}	6.1×10^{-4}	6.1×10^{-3}	3.2×10^{-12}	1.1×10^{4}
47	Ag^{111}	3.1×10^{-6}	7.7×10^{-5}	7.7×10^{-4}	2.0×10^{-14}	3.2×10^{5}
48	Cd^{109}+Ag^{109m}	2.1×10^{-4}	5.7×10^{-4}	5.3×10^{-3}	8.2×10^{-11}	4.8×10^{3}
50	Sn^{113}	4.4×10^{-4}	1.8×10^{-3}	1.7×10^{-2}	4.2×10^{-11}	2.3×10^{3}
52	Te^{127}	3.2×10^{-6}	1.3×10^{-5}	1.3×10^{-4}	3.6×10^{-13}	3.1×10^{5}
52	Te^{129}	1.4×10^{-6}	1.2×10^{-5}	1.2×10^{-4}	4.6×10^{-14}	7.1×10^{5}

TABLE III

(cont'd)

(1)	Isotope	(2) 0.3 rem in 1 wk	(3) 15.7 rem in 1 yr	(4) 150 rem in 70 yrs	(5) (mg)	(6) H
53	I^{131}	6.8×10^{-6}	1.5×10^{-4}	1.5×10^{-3}	5.0×10^{-14}	1.6×10^{5}
55	$Cs^{137}+Ba^{137a}$	4.7×10^{-6}	1.1×10^{-5}	9.5×10^{-5}	5.9×10^{-11}	2.1×10^{5}
56	$Ba^{140}+La^{140}$	1.3×10^{-6}	2.1×10^{-5}	2.1×10^{-4}	1.8×10^{-14}	7.7×10^{5}
57	La^{140}	4.8×10^{-6}	2.2×10^{-4}	2.2×10^{-3}	8.5×10^{-15}	2.1×10^{5}
58	$Ce^{144}+Pr^{144}$	6.9×10^{-7}	2.0×10^{-6}	1.9×10^{-5}	2.2×10^{-13}	1.4×10^{6}
59	Pr^{143}	3.3×10^{-6}	5.4×10^{-5}	5.4×10^{-4}	4.9×10^{-14}	3.0×10^{5}
61	Pm^{147}	1.3×10^{-5}	3.1×10^{-5}	2.8×10^{-4}	1.4×10^{-11}	7.7×10^{4}
62	Sm^{151}	4.3×10^{-5}	9.6×10^{-5}	8.4×10^{-4}	1.8×10^{-9}	2.3×10^{4}
63	Eu^{154}	4.1×10^{-6}	9.2×10^{-6}	8.2×10^{-5}	2.8×10^{-11}	2.4×10^{5}
67	Ho^{166}	5.7×10^{-6}	2.8×10^{-4}	2.8×10^{-3}	8.2×10^{-15}	1.8×10^{5}
69	Tm^{170}	2.7×10^{-6}	10^{-5}	10^{-4}	4.4×10^{-13}	3.7×10^{5}
71	Lu^{177}	9.2×10^{-6}	2.4×10^{-4}	2.4×10^{-3}	8.4×10^{-14}	1.1×10^{5}
73	Ta^{182}	5.1×10^{-6}	2.1×10^{-5}	2.1×10^{-4}	7.8×10^{-13}	2.0×10^{5}
74	W^{181}	2.9×10^{-5}	1.1×10^{-4}	10^{-3}	5.6×10^{-12}	3.4×10^{4}
75	Re^{183}	2.9×10^{-4}	1.1×10^{-3}	1.1×10^{-2}	4.8×10^{-11}	3.4×10^{3}
77	Ir^{190}	3.1×10^{-5}	6.1×10^{-4}	6.1×10^{-3}	4.8×10^{-13}	3.2×10^{4}
77	Ir^{192}	4.0×10^{-6}	2.0×10^{-5}	2.0×10^{-4}	4.3×10^{-13}	2.5×10^{5}
78	Pt^{191}	2.9×10^{-4}	1.2×10^{-2}	1.2×10^{-1}	1.3×10^{-12}	3.4×10^{3}
78	Pt^{193}	2.8×10^{-4}	9.6×10^{-3}	9.6×10^{-2}	1.8×10^{-12}	3.6×10^{3}
79	Au^{196}	2.6×10^{-4}	7.6×10^{-3}	7.6×10^{-2}	2.1×10^{-13}	3.8×10^{3}
79	Au^{198}	5.8×10^{-6}	2.4×10^{-4}	2.4×10^{-3}	2.3×10^{-14}	1.7×10^{5}
79	Au^{199}	1.6×10^{-5}	6.3×10^{-4}	6.3×10^{-3}	8.0×10^{-14}	6.3×10^{4}

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TABLE III

(cont'd)

(1)	Isotope	(2) 0.3 rem in 1 wk	(3) 15.7 rem in 1 yr	(4) 150 rem in 70 yrs	(5) (mg)	(6) H
81	Tl^{200}	3.3×10^{-5}	1.6×10^{-3}	1.6×10^{-2}	5.7×10^{-14}	3.9×10^{4}
81	Tl^{201}	2.9×10^{-3}	1.2×10^{-1}	1.2	1.3×10^{-11}	3.4×10^{2}
81	Tl^{202}	1.0×10^{-4}	1.8×10^{-3}	1.8×10^{-2}	1.8×10^{-12}	10^{4}
81	Tl^{204}	3.4×10^{-6}	8.1×10^{-6}	7.3×10^{-5}	7.9×10^{-12}	2.9×10^{5}
82	Pb^{203}	2.1×10^{-4}	9.5×10^{-3}	9.5×10^{-2}	7.0×10^{-13}	4.8×10^{3}
82	Pb^{210} +dr	1.5×10^{-8}	3.5×10^{-8}	3.1×10^{-7}	1.9×10^{-13}	6.7×10^{7}
84	Po^{210}	1.6×10^{-8}	5.9×10^{-8}	5.8×10^{-7}	3.5×10^{-15}	6.3×10^{7}
85	At^{211}	1.8×10^{-7}	9.2×10^{-6}	9.2×10^{-5}	8.9×10^{-17}	5.6×10^{6}
88	Ra^{226} +dr	5.3×10^{-9}	1.2×10^{-8}	1.0×10^{-7}	5.4×10^{-12}	1.9×10^{5}
89	Ac^{227} +dr	2.5×10^{-9}	5.8×10^{-9}	5.1×10^{-8}	3.5×10^{-14}	4.0×10^{8}
90	Th - nat	2.3×10^{-9}	5.1×10^{-9}	4.5×10^{-8}	2.0×10^{-5}	5.0×10^{-3}
90	Th^{234} + Pa^{234}	1.1×10^{-6}	1.2×10^{-5}	1.2×10^{-4}	4.7×10^{-14}	9.1×10^{5}
92	U - nat	9.1×10^{-9}	2.0×10^{-8}	1.8×10^{-7}	2.7×10^{-5}	3.7×10^{-3}
92	U^{233}	1.7×10^{-8}	3.8×10^{-8}	3.4×10^{-7}	1.8×10^{-9}	5.9×10^{3}
94	Pu^{239}	1.6×10^{-8}	3.6×10^{-8}	3.2×10^{-7}	2.6×10^{-10}	3.8×10^{4}
95	Am^{241}	1.5×10^{-8}	3.4×10^{-8}	3.0×10^{-7}	4.9×10^{-12}	2.0×10^{6}
96	Cm^{242}	1.4×10^{-8}	4.6×10^{-8}	4.7×10^{-7}	4.2×10^{-15}	7.1×10^{7}

(s) The daughter products in these cases are isomers in an excited state.

TABLE IV

SINGLE EXPOSURE VALUES FOR INHALATION OF INSOLUBLE RADIOACTIVE MATERIALS WHEN THE LUNG IS THE CRITICAL BODY ORGAN

Z	(1) Isotope	(2) MPI* or μc inhaled in 8 hours that will result in a dose of: 0.3 rem in 1 week	(3) 15.7 rem in 1 year	(4) 150 rem in 70 years	(5) μg corresponging to smallest value in columns 2, 3, or 4	(6) Relative Hazard H
1	H^3 (HTO or H_2^3O)	1.1×10^3	2.7×10^3	2.3×10^4	1.2×10^{-4}	9.0×10^{-4}
4	Be^7	1.9×10^2	1.2×10^3	1.2×10^4	5.7×10^{-7}	5.1×10^{-3}
6	C^{14} (CO_2)	1.3×10^2	3.0×10^2	2.6×10^3	2.9×10^{-2}	3.6×10^{-3}
9	F^{18}	5.3×10^3	2.8×10^5	2.7×10^6	5.7×10^{-8}	1.9×10^{-4}
11	Na^{24}	23	1.2×10^3	1.1×10^4	2.6×10^{-9}	4.5×10^{-2}
15	P^{32}	12	1.9×10^2	1.8×10^3	4.3×10^{-8}	8.4×10^{-2}
16	S^{35}	1.3×10^2	6.3×10^2	6.0×10^3	2.9×10^{-6}	7.8×10^{-3}
17	Cl^{36}	26	63	5.3×10^2	1.1	9.3×10^{-5}
19	K^{42}	50	2.5×10^3	2.4×10^4	8.3×10^{-9}	2.0×10^{-2}
20	Ca^{45}	80	3.0×10^2	2.8×10^3	4.3×10^{-6}	1.3×10^{-2}
21	Sc^{46}	5.7	26	2.5×10^2	1.7×10^{-7}	0.18
21	Sc^{47}	63	2.5×10^3	2.4×10^4	7.7×10^{-8}	1.6×10^{-2}
21	Sc^{48}	13	6.3×10^2	3.7×10^3	8.7×10^{-9}	7.8×10^{-2}
23	V^{48}	4.7	67	6.7×10^2	2.7×10^{-8}	0.21
24	Cr^{51}	6.7×10^2	6.7×10^3	6.3×10^4	7.3×10^{-6}	1.5×10^{-3}
25	Mn^{56}	4×10^2	2.1×10^4	2.0×10^5	1.8×10^{-8}	2.5×10^{-3}
26	Fe^{55}	1.1×10^3	2.9×10^3	2.5×10^4	5.3×10^{-4}	8.7×10^{-4}
26	Fe^{59}	9	63	6.0×10^2	1.8×10^{-7}	0.11
27	Co^{60}	4.7	11	97	4.0×10^{-6}	0.21
28	Ni^{59}	1.4×10^2	3.2×10^2	2.7×10^3	1.8	5.7×10^{-5}
29	Cu^{64}	3.7×10^2	1.8×10^4	1.8×10^5	9.7×10^{-8}	2.7×10^{-3}

* The MPI as used here is the μc present initially in a volume of air to be breathed during the succeeding 8 hours and which then results in the indicated dose.

TABLE IV
(cont'd)

Z	(1) Isotope	(2) 0.3 rem in 1 wk	(3) 15.7 rem in 1 yr	(4) 150 rem in 70 yrs	(5) (mg)	(6) H
30	Zn^{65}	21	67	6.0×10^{2}	2.5×10^{-6}	4.8×10^{-2}
31	Ga^{72}	33	1.7×10^{3}	1.7×10^{4}	1.1×10^{-8}	3.9×10^{-2}
32	Ge^{71}	8.7×10^{2}	1.7×10^{4}	1.6×10^{5}	5.3×10^{-6}	1.1×10^{-3}
33	As^{76}	25	1.3×10^{3}	1.3×10^{4}	1.6×10^{-8}	3.9×10^{-2}
37	Rb^{86}	11	1.4×10^{2}	1.3×10^{3}	1.4×10^{-7}	9.3×10^{-2}
38	Sr^{89}	13	83	8.0×10^{2}	4.7×10^{-7}	7.8×10^{-2}
38	$Sr^{90} + Y^{90}$	7	16	1.4×10^{2}	3.3×10^{-5}	0.14
39	Y^{91}	13	77	7.3×10^{2}	5.0×10^{-7}	7.8×10^{-2}
40	$Zr^{95} + Nb^{95}$	7.3	43	4.0×10^{2}	3.3×10^{-7}	0.14
41	Nb^{95}	14	1.2×10^{2}	1.2×10^{3}	3.7×10^{-7}	6.9×10^{-2}
42	Mo^{99}	28	1.2×10^{3}	1.2×10^{4}	6.0×10^{-8}	3.6×10^{-2}
43	Tc^{96}	8	2.8×10^{2}	2.7×10^{3}	2.5×10^{-8}	0.13
44	$Ru^{106} + Rh^{106}$	4.7	13	1.2×10^{2}	1.4×10^{-6}	0.21
45	Rh^{105}	23	2.6×10^{3}	2.5×10^{4}	6.3×10^{-8}	1.9×10^{-2}
46	$Pd^{103} + Rh^{103m}$	1.1×10^{2}	1.5×10^{3}	1.5×10^{4}	1.4×10^{-6}	9.3×10^{-3}
47	Ag^{105}	4.3	30	2.9×10^{2}	1.6×10^{-7}	0.23
47	Ag^{111}	26	6.7×10^{2}	6.3×10^{3}	1.7×10^{-7}	3.9×10^{-2}
48	$Cd^{109} + Ag^{109m}$	27	2.7×10^{2}	2.4×10^{3}	4.0×10^{-5}	1.0×10^{-2}
50	Sn^{113}	23	97	9.0×10^{2}	2.2×10^{-6}	4.5×10^{-2}
52	Te^{127}	22	90	8.7×10^{2}	2.4×10^{-6}	4.5×10^{-2}
52	Te^{129}	5.3	47	4.3×10^{2}	1.8×10^{-7}	0.19
53	I^{131}	22	5.3×10^{2}	5.0×10^{3}	1.7×10^{-7}	4.5×10^{-2}
55	$Cs^{137} + Ba^{137m}$	12	29	2.4×10^{2}	1.5×10^{-4}	8.4×10^{-2}
56	$Ba^{140} + La^{140}$	4.3	77	7.3×10^{2}	6.0×10^{-8}	0.23
57	La^{140}	15	7.0×10^{2}	6.7×10^{3}	2.6×10^{-8}	6.9×10^{-2}

TABLE IV
(cont'd)

Z	(1) Isotope	(2) 0.3 rem in 1 wk	(3) 15.7 rem in 1 yr	(4) 150 rem in 70 yrs	(5) (mg)	(6) E
58	$Ce^{144} + Pr^{144}$	5	15	1.4×10^{2}	1.6×10^{-6}	0.20
59	Pr^{143}	27	4.7×10^{2}	4.3×10^{3}	4.0×10^{-7}	3.6×10^{-2}
61	Pm^{147}	1.0×10^{2}	2.6×10^{2}	2.3×10^{3}	1.1×10^{-4}	9.6×10^{-3}
62	Sm^{151}	3.3×10^{2}	8.0×10^{2}	6.7×10^{3}	1.4×10^{-2}	3×10^{-3}
63	Eu^{154}	8.3	20	1.7×10^{2}	5.7×10^{-5}	0.12
67	Ho^{166}	47	2.4×10^{3}	2.3×10^{4}	6.7×10^{-8}	2.1×10^{-2}
69	Tm^{170}	22	87	8.3×10^{2}	3.7×10^{-6}	4.5×10^{-2}
71	Lu^{177}	57	1.6×10^{3}	1.5×10^{4}	5.3×10^{-7}	1.8×10^{-2}
73	Ta^{182}	8.7	37	3.3×10^{2}	1.3×10^{-6}	0.11
74	W^{181}	6.3	25	2.3×10^{2}	1.2×10^{-6}	0.16
75	Re^{183}	11	47	4.3×10^{2}	1.8×10^{-6}	9.0×10^{-2}
77	Ir^{190}	43	8.7×10^{2}	8.0×10^{3}	6.7×10^{-7}	2.3×10^{-2}
77	Ir^{192}	7.3	37	3.7×10^{2}	8.0×10^{-7}	0.14
78	Pt^{191}	12	5.0×10^{2}	4.7×10^{3}	5.3×10^{-8}	8.4×10^{-2}
78	Pt^{193}	12	4.0×10^{2}	4.0×10^{3}	7.3×10^{-8}	8.7×10^{-2}
79	Au^{196}	28	8.7×10^{2}	8.3×10^{3}	2.3×10^{-7}	3.6×10^{-2}
79	Au^{198}	27	1.2×10^{3}	1.1×10^{4}	1.1×10^{-7}	3.6×10^{-2}
79	Au^{199}	63	2.5×10^{3}	2.4×10^{4}	3.2×10^{-7}	1.7×10^{-2}
81	Tl^{200}	26	1.4×10^{3}	1.3×10^{4}	4.7×10^{-8}	3.9×10^{-2}
81	Tl^{201}	90	3.7×10^{3}	3.7×10^{4}	4.0×10^{-7}	1.1×10^{-2}
81	Tl^{202}	40	7.3×10^{2}	7.0×10^{3}	7.3×10^{-7}	2.5×10^{-2}
81	Tl^{204}	27	67	6.0×10^{2}	6.3×10^{-5}	3.6×10^{-2}
82	Pb^{203}	37	1.7×10^{3}	1.6×10^{4}	1.2×10^{-7}	2.7×10^{-2}

TABLE IV

(cont'd)

Z	(1) Isotope	(2) 0.3 rem in 1 wk	(3) 15.7 rem in 1 yr	(4) 150 rem in 70 yrs	(5) (mg)	(6) H
82	Pb^{210}	0.11	0.29	2.5	1.6×10^{-6}	8.1
84	Po^{210}	0.12	0.47	4.7	2.7×10^{-8}	8.1
85	At^{211}	3.1	1.1×10^{2}	1.0×10^{3}	1.0×10^{-9}	0.48
88	Ra^{226} + dr	2.8×10^{-2}	6.3×10^{-2}	0.53	2.8×10^{-5}	3.6
89	Ac^{227} + dr	2.1×10^{-2}	4.7×10^{-2}	0.40	2.9×10^{-7}	48
90	Th-nat	1.9×10^{-2}	4.3×10^{-2}	0.37	1.6×10^{2}	6.3×10^{-7}
90	Th^{234} + Pa^{234}	8.3×10^{-2}	97	9.0×10^{2}	3.7×10^{9}	0.12
92	U-nat	7.3×10^{-2}	0.17	1.4	2.2×10^{2}	4.5×10^{-7}
92	U^{233}	0.14	0.32	2.7	1.5×10^{-2}	6.9×10^{-3}
94	Pu^{239}	0.13	0.30	2.5	2.1×10^{-3}	4.8×10^{-2}
95	Am^{241}	0.12	0.29	2.4	4.0×10^{-5}	2.5
96	Cm^{242}	0.11	0.40	3.7	3.2×10^{-8}	9.3×10^{-2}

(s) The daughter products in these cases are isomers in an excited state.

TABLE V

SINGLE EXPOSURE VALUES FOR INHALATION OF INSOLUBLE RADIOACTIVE MATERIAL WHEN THE GI TRACT IS THE CRITICAL BODY ORGAN

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			MPC* or μc inhaled in 8 hours that will deliver a dose of 0.3 rem during the following week to the organs cited: Eqs. (26),(28)				mg corresponding to smallest value in columns 4, 5,6, or 7	Relative Hazard H
Z	Isotope	mg/100 mc	Stomach	Small Intestine	Upper Large Intestine	Lower Large Intestine		
1	H^3(HTO or H_3^2O)	10^{-2}	1.9×10^4	2.1×10^4	2.5×10^4	1.2×10^4	1.2×10^{-3}	8.3×10^{-5}
4	Be^7	2.9×10^{-4}	7.0×10^3	3.3×10^3	8.5×10^2	4.2×10^2	1.2×10^{-6}	2.4×10^{-3}
6	$C^{14}(CO_2)$	22	2.1×10^3	2.3×10^3	2.9×10^3	1.4×10^3	0.31	3.2×10^{-4}
9	F^{18}	1.1×10^{-6}	1.7×10^3	2.3×10^3	1.1×10^{15}	10^{16}	1.9×10^{-8}	5.8×10^{-4}
11	Na^{24}	1.2×10^{-5}	92	57	8.7×10^2	6.2×10^2	6.6×10^{-9}	1.8×10^{-2}
15	P^{32}	3.5×10^{-4}	1.7×10^2	1.8×10^2	38	19	6.6×10^{-8}	5.3×10^{-2}
16	S^{35}	2.3×10^{-3}	2.0×10^3	2.2×10^3	3.1×10^2	1.6×10^2	3.7×10^{-6}	6.3×10^{-3}
17	Cl^{36}	4.1×10^3	4.3×10^2	4.8×10^2	5.8×10^2	2.9×10^2	12	8.4×10^{-6}
19	K^{42}	1.7×10^{-5}	98	102	1.1×10^3	8.5×10^2	1.6×10^{-8}	10^{-2}
20	Ca^{45}	5.6×10^{-3}	1.3×10^3	1.5×10^3	9.0×10^2	4.4×10^2	2.5×10^{-5}	2.3×10^{-3}
21	Sc^{46}	3.0×10^{-3}	2.2×10^2	95	19	9.2	2.7×10^{-7}	0.11
21	Sc^{47}	1.2×10^{-4}	5.6×10^2	6.1×10^2	39	21	2.6×10^{-8}	4.8×10^{-2}
21	Sc^{48}	6.7×10^{-5}	1.5×10^2	84	16	9.1	6.1×10^{-9}	0.11
23	V^{48}	5.8×10^{-4}	1.3×10^2	69	14	7.1	4.1×10^{-8}	0.14
24	Cr^{51}	1.1×10^{-3}	1.4×10^4	1.1×10^4	10^3	5.0×10^2	5.4×10^{-6}	2.0×10^{-3}
25	Mn^{56}	4.6×10^{-6}	2.9×10^2	2.2×10^2	80	3.4×10^2	3.6×10^{-9}	1.2×10^{-2}
26	Fe^{55}	4.6×10^{-2}	1.9×10^4	2.1×10^4	6.3×10^3	3.1×10^3	1.4×10^{-3}	3.2×10^{-4}
26	Fe^{59}	2.0×10^{-3}	2.7×10^2	1.5×10^2	1.4×10^2	68	1.4×10^{-6}	1.5×10^{-2}
27	Co^{60}	8.7×10^{-2}	1.6×10^2	82	22	11	9.5×10^{-6}	9.1×10^{-2}
28	Ni^{59}	1.3×10^3	2.2×10^3	2.5×10^3	1.9×10^2	94	1.2	8.2×10^{-5}

* The MPI as used here is the μc present initially in a volume of air to be breathed during the succeeding 8 hours and which then results in the indicated dose.

TABLE V

(cont'd)

(1) Z	(2) Isotope	(3) mg/100 mc	(4) Stomach	(5) Small Intestine	(6) Upper Large Intestine	(7) Lower Large Intestine	(8) mg	(9) Relative Hazard H
29	Cu^{64}	2.6×10^{-5}	9.5×10^{2}	7.6×10^{2}	1.4×10^{2}	1.1×10^{2}	2.8×10^{-8}	9.8×10^{-3}
30	Zn^{65}	1.2×10^{-2}	7.5×10^{2}	3.7×10^{2}	99	49	5.9×10^{-6}	2.0×10^{-2}
31	Ga^{72}	3.2×10^{-5}	1.2×10^{2}	79	15	11	3.5×10^{-9}	9.1×10^{-2}
32	Ge^{71}	6.2×10^{-4}	1.1×10^{4}	1.2×10^{4}	7.8×10^{2}	3.9×10^{2}	2.4×10^{-6}	2.6×10^{-3}
33	As^{76}	6.4×10^{-5}	1.1×10^{2}	1.1×10^{2}	9.0	5.4	3.4×10^{-9}	0.18
37	Rb^{86}	1.3×10^{-3}	1.7×10^{2}	1.7×10^{2}	2.5×10^{2}	1.3×10^{2}	1.7×10^{-6}	7.7×10^{-3}
38	Sr^{89}	3.6×10^{-3}	2.0×10^{2}	2.3×10^{2}	35	17	6.1×10^{-7}	5.9×10^{-2}
39	Y^{90}	1.7×10^{-4}	1.3×10^{2}	1.5×10^{2}	9.6	5.2	9.1×10^{-9}	0.19
38	Sr^{90}+Y^{90}	0.5	6.1×10^{2}	6.5×10^{2}	58	21	1.0×10^{-4}	4.8×10^{-2}
39	Y^{91}	4.0×10^{-3}	2.0×10^{2}	2.2×10^{2}	13	6.6	2.6×10^{-7}	0.15
41	Nb^{95}	2.5×10^{-3}	4.5×10^{2}	2.4×10^{2}	93	46	1.2×10^{-6}	2.2×10^{-2}
40	Zr^{95}+Nb^{95}	4.7×10^{-3}	3.5×10^{2}	2.2×10^{2}	33	16	7.5×10^{-7}	6.2×10^{-2}
42	Mo^{99}	2.2×10^{-4}	4.0×10^{2}	2.5×10^{2}	1.4×10^{2}	72	1.6×10^{-7}	1.3×10^{-2}
43	Tc^{96}	3.1×10^{-4}	1.7×10^{2}	85	44	24	7.2×10^{-8}	4.2×10^{-2}
44	Ru^{106}+Rh^{106}	2.9×10^{-2}	80	82	5.4	2.7	7.9×10^{-7}	0.37
45	Rh^{105}	1.2×10^{-4}	3.5×10^{2}	2.9×10^{2}	38	22	2.6×10^{-8}	4.6×10^{-2}
45	Rh^{103s}	3.0×10^{-5}	2.3×10^{4}	2.8×10^{4}	3.7×10^{5}	6.4×10^{7}	7.0×10^{-6}	4.3×10^{-5}
46	Pd^{103}+Rh^{103s}	1.3×10^{-3}	6.4×10^{3}	2.4×10^{3}	2.4×10^{2}	1.2×10^{2}	1.6×10^{-6}	8.3×10^{-3}
47	Ag^{105}	3.6×10^{-3}	1.5×10^{2}	73	19	9.4	3.4×10^{-7}	0.11
47	Ag^{111}	6.3×10^{-4}	3.0×10^{2}	3.4×10^{2}	21	11	7.0×10^{-8}	9.1×10^{-2}
48	Cd^{109}+Ag^{109}	3.9×10^{-2}	2.8×10^{3}	1.8×10^{3}	2.5×10^{2}	1.3×10^{2}	5.1×10^{-5}	7.7×10^{-3}
50	Sn^{113}	9.6×10^{-3}	7.5×10^{2}	4.0×10^{2}	88	44	4.2×10^{-6}	2.3×10^{-2}
52	Te^{127}	1.1×10^{-2}	3.9×10^{2}	3.9×10^{2}	36	18	2.0×10^{-6}	5.5×10^{-2}

TABLE V
(cont'd)

(1) Z	(2) Isotope	(3) mg/100 mc	(4) Stomach	(5) Small Intestine	(6) Upper Large Intestine	(7) Lower Large Intestine	(8) mg	(9) Relative Hazard, H
52	Te^{129}	3.3×10^{-3}	1.1×10^{2}	88	12	6.1	2.0×10^{-7}	0.16
53	I^{131}	8.0×10^{-4}	3.8×10^{2}	2.9×10^{2}	7.0×10^{2}	3.5×10^{2}	2.3×10^{-6}	3.4×10^{-3}
55	Cs^{137} + Ba^{137s}	1.3	3.2×10^{2}	2.2×10^{2}	5.6×10^{2}	2.8×10^{2}	2.7×10^{-3}	4.5×10^{-3}
57	La^{140}	1.8×10^{-4}	1.3×10^{2}	90	12	6.6	1.2×10^{-8}	0.15
56	Ba^{140} + La^{140}	1.4×10^{-3}	3.3×10^{2}	2.6×10^{2}	19	7	9.5×10^{-8}	0.14
59	Pr^{144}	1.3×10^{-6}	4.5×10^{3}	1.9×10^{4}	2.8×10^{7}	2.5×10^{15}	6.1×10^{-8}	2.2×10^{-4}
58	Ce^{144} + Pr^{144}	3.2×10^{-2}	1.3×10^{2}	91	5.9	2.9	9.2×10^{-7}	0.34
59	Pr^{143}	1.5×10^{-3}	3.6×10^{2}	4.0×10^{2}	25	13	2.0×10^{-7}	7.7×10^{-2}
61	Pm^{147}	0.11	1.7×10^{3}	1.8×10^{3}	1.1×10^{2}	56	5.9×10^{-5}	1.8×10^{-2}
62	Sm^{151}	4.2	5.6×10^{3}	6.2×10^{3}	3.8×10^{2}	1.9×10^{2}	8.0×10^{-3}	5.3×10^{-3}
63	Eu^{154}	0.68	2.4×10^{2}	1.5×10^{2}	22	11	7.5×10^{-5}	9.1×10^{-2}
67	Ho^{166}	1.4×10^{-4}	1.9×10^{2}	2.1×10^{2}	17	10	1.4×10^{-8}	0.10
69	Tm^{170}	1.6×10^{-2}	3.5×10^{2}	3.9×10^{2}	24	12	2.0×10^{-6}	8.3×10^{-2}
71	Lu^{177}	9.2×10^{-4}	8.1×10^{2}	7.3×10^{2}	55	28	2.6×10^{-7}	3.6×10^{-2}
73	Ta^{182}	1.5×10^{-2}	2.6×10^{2}	1.5×10^{2}	25	12	1.8×10^{-6}	8.4×10^{-2}
74	W^{181}	1.9×10^{-2}	2.4×10^{2}	1.1×10^{2}	32	16	3.1×10^{-6}	6.3×10^{-2}
75	Re^{183}	1.7×10^{-2}	4.0×10^{2}	2.0×10^{2}	10^{2}	50	8.3×10^{-6}	2.0×10^{-2}
77	Ir^{190}	1.6×10^{-3}	1.2×10^{3}	6.2×10^{2}	1.6×10^{2}	81	1.3×10^{-6}	1.2×10^{-2}
77	Ir^{192}	1.1×10^{-2}	2.0×10^{2}	1.3×10^{2}	24	12	1.3×10^{-6}	8.4×10^{-2}
78	Pt^{191}	4.4×10^{-4}	2.2×10^{2}	10^{2}	33	18	7.7×10^{-8}	5.7×10^{-2}
78	Pt^{193}	6.3×10^{-4}	2.4×10^{2}	1.2×10^{2}	40	21	1.3×10^{-7}	4.8×10^{-2}
79	Au^{196}	8.3×10^{-4}	6.7×10^{2}	3.4×10^{2}	98	51	4.2×10^{-7}	2.0×10^{-2}
79	Au^{198}	4.1×10^{-4}	2.7×10^{2}	2.3×10^{2}	25	14	5.5×10^{-8}	7.4×10^{-2}

TABLE V
(cont'd)

(1) Z	(2) Isotope	(3) μg/100 mc	(4) Stomach	(5) Small Intestine	(6) Upper Large Intestine	(7) Lower Large Intestine	(8) μg	(9) Relative Hazard H
79	Au^{199}	5.0×10^{-4}	7.4×10^{2}	5.9×10^{2}	77	40	2.0×10^{-7}	2.5×10^{-2}
81	Tl^{200}	1.7×10^{-4}	2.1×10^{2}	1.1×10^{2}	51	31	5.3×10^{-8}	3.3×10^{-2}
81	Tl^{201}	4.6×10^{-4}	1.7×10^{3}	8.1×10^{2}	4.1×10^{2}	2.2×10^{2}	9.4×10^{-6}	4.6×10^{-3}
81	Tl^{202}	1.8×10^{-3}	1.1×10^{3}	5.9×10^{2}	2.4×10^{2}	1.2×10^{2}	2.2×10^{-6}	8.4×10^{-3}
81	Tl^{204}	0.23	4.5×10^{2}	5.0×10^{2}	55	27	6.3×10^{-5}	3.7×10^{-2}
82	Pb^{203}	3.4×10^{-4}	5.4×10^{2}	2.6×10^{2}	84	46	1.6×10^{-7}	2.2×10^{-2}
84	Po^{210}	2.2×10^{-2}	2.0	2.2	0.16	6.4×10^{-2}	1.4×10^{-8}	16
83	Bi^{210} Po^{210+}	8.0×10^{-4}	2.9×10^{2}	2.8×10^{2}	15	5.8	4.6×10^{-8}	0.17
82	$Pb^{210} \rightarrow Po^{210}$	1.3	4.5×10^{3}	2.6×10^{3}	1.7×10^{2}	39	5.0×10^{-4}	2.6×10^{-2}
85	$At^{211} \rightarrow Pb^{207}$	5.0×10^{-5}	2.4	2.7	3.1×10^{2}	3.3×10^{2}	8.2×10^{-9}	0.42
83	$Bi^{214} \rightarrow Po^{210}$	2.2×10^{-6}	56	2.2×10^{2}	7.9×10^{4}	6.7×10^{6}	1.2×10^{-9}	1.8×10^{-2}
82	$Pb^{214} \rightarrow Po^{210}$	3.0×10^{-6}	[illegible]	55	1.1×10^{4}	4.3×10^{6}	1.5×10^{-9}	2.0×10^{-2}
86	$Rn^{222} \rightarrow Po^{210}$	6.5×10^{-4}	0.81	0.76	4.0×10^{-2}	2.1×10^{-2}	1.4×10^{-2}	
88	$Ra^{226} \rightarrow Po^{210}$	10^{2}	2.3	2.5	0.14	5.1×10^{-2}	5.2×10^{-5}	1.9
82	Pb^{211}	4.0×10^{-6}	257	52	2.0×10^{4}	10^{8}	10^{-9}	4.0×10^{-2}
88	$Ra^{223} \rightarrow Pb^{211}$	1.9×10^{-3}	0.48	0.49	3.5×10^{-2}	1.8×10^{-2}	3.4×10^{-10}	56
90	$Th^{227} \rightarrow Pb^{211}$	3.2×10^{-3}	1.8	1.9	0.11	4.7×10^{-2}	1.5×10^{-9}	21
89	$Ac^{227} \rightarrow Pb^{211}$	1.4	2.1×10^{3}	2.5×10^{2}	5.7	1.1	1.5×10^{-5}	0.91
83	Bi^{212}	6.8×10^{-6}	10	17	16	1.9×10^{3}	7.2×10^{-10}	9.6×10^{-2}
82	Pb^{212} Bi^{212+}	7.1×10^{-5}	6.4	2.6	0.18	0.15	1.1×10^{-10}	6.5
88	$Ra^{224} \rightarrow Bi^{212}$	6.2×10^{-4}	0.58	0.64	4.4×10^{-2}	2.2×10^{-2}	1.4×10^{-10}	45
90	$Th^{228} \rightarrow Bi^{212}$	0.12	2.0	2.0	0.10	3.5×10^{-2}	4.2×10^{-8}	29

TABLE V

(cont'd)

(1) Z	(2) Isotope	(3) mg/100 mc	(4) Stomach	(5) Small Intestine	(6) Upper large Intestine	(7) Lower Large Intestine	(8) mg	(9) Relative Hazard H
89	$Ac^{228} \rightarrow Bi^{212}$	4.4×10^{-5}	2.3×10^{2}	2.0×10^{2}	30	33	1.3×10^{-8}	3.3×10^{-2}
88	$Ra^{228} \rightarrow Bi^{212}$	0.43	2.0×10^{3}	2.8×10^{2}	17	6.4	2.7×10^{-5}	0.16
90	$Th^{232} \rightarrow Bi^{212}$	8.8×10^{8}	2.7	3.0	0.19	9.2×10^{-2}	8.1×10^{2}	1.2×10^{-7}
90	$Th^{234}_{+Pa^{234}}$	4.3×10^{-3}	1.3×10^{2}	1.4×10^{2}	8.8	4.4	1.9×10^{-7}	0.23
92	U^{238}	3.0×10^{8}	2.6	2.9	0.18	0.10	7.7×10^{3}	1.3×10^{-8}
92	U^{234}	1.6×10^{4}	2.3	2.5	0.15	7.7×10^{-2}	1.2×10^{-2}	8.1×10^{-3}
92	U^{235}	4.6×10^{7}	2.5	2.7	0.17	8.0×10^{-2}	1.2×10^{3}	8.6×10^{-8}
92	U^{233}	1.1×10^{4}	2.2	2.5	0.15	7.5×10^{-2}	7.9×10^{-3}	1.3×10^{-2}
94	Pu^{239}	1.6×10^{3}	2.1	2.3	0.14	7.1×10^{-2}	1.1×10^{-3}	8.8×10^{-2}
95	Am^{241}	33	2.0	2.2	0.14	6.7×10^{-2}	2.2×10^{-5}	4.6
96	Cm^{242}	3.0×10^{-2}	1.8	2.0	0.12	6.0×10^{-2}	1.8×10^{-8}	17

(s) The daughter products in these cases are isomers in an excited state.

The arrow ($\longrightarrow$) means the values given include the energies emitted by all the daughter products down to the stable isotope.

TABLE VI

General Information Relative to Shipments of Radioactive Material from Oak Ridge National Laboratory[8]

(1) Radioisotope	(2) Compound as Shipped	(3) Specific Activity	(4) Form and Physical Character	(5) Estimate of Probable Fraction Available for Inhalation (%)
H-3 (P)	H + He^3 Gas	~2.63 c/cc at NTP (CF)	Gas	100
Be-7 (P)	$BeCl_2$	>0.5 mc/ml (CF)	In HCl solution	1 (fumes)
C-14 (P)1	$BaCO_3$	0.25–1.5 c/g C	Powder	1 (dust)
Na-22 (P)	NaCl	>1 c/g Na (CF)	In weak HCl solution	0.1
Na-24 (I)	Na_2CO_3	90 mc/g Na	Powder	1
Na-24 (P)	NaCl	~1 c/g Na	In H_2O solution	0.1
P-32 (I)	KH_2PO_4	30 mc/g P	Crystalline-fine	0.1
P-32 (P)1	Phosphate	~0.025 mg P/mc	In weak HCl solution	0.1
P-32 (P)2	Phosphate	>0.5 mc/ml (CF)	In weak HCl solution	0.1
S-35 (I)	S (elemental)	0.3 mc/g S	Sulfur sublimed	1
S-35 (P)1	Sulfate	>1 mc/ml (CF)	In weak HCl solution	0.1
S-35 (P)2	Ba sulfide	>10 c/g S	In $Ba(OH)_2$ solution	1
S-35 (P)3	S (elemental)	>1 c/g S	In benzene solution	1
Cl-36 (I)	KCl	0.0006 mc/g Cl	Crystalline (very fine)	0.1
Cl-36 (P)	HCl	0.01–0.2 mc/g Cl	HCl solution	1
A-37 (P)	Argon and helium	0.01–0.1 mc/ml (CF)	Gas	100
K-42 (I)	K_2CO_3	20 mc/g K	Anhydrous powder	1
Ca-45 (I)	$CaCO_3$	0.4 mc/g Ca	Powder	1 (dust)
Ca-45 (P)1	$CaCl_2$	0.2–0.4 mc/g Ca	In HCl solution	Slight
Ca-45 (P)2	$CaCl_2$	5–60 mc/g Ca	In HCl solution	Slight
Ca-45 (P)3	$CaCl_2$	>1000 mc/g	In HCl solution	Slight
Ca-45 (P)4	Chloride	>0.1 μc/ml (CF)	In HCl solution	Slight
Sc-46 (I)	Sc_2O_3	750 mc/g Sc	Powder	0.2
Sc-46 (P)	$ScCl_3$	>5 c/g Sc	In HCl solution	0.1
Cr-51 (I)	Cr metal	50 mc/g Cr	Metal powder	Slight
Cr-51 (P)	$CrCl_3$	100–400 mc/g Cr	In HCl solution	0.1
Mn-52–54 (P)	$MnCl_2$	>0.05 mc/ml (CF)	In HCl solution	0.1
Fe-55–59 (I)	Fe metal	0.7, 0.4 mc/g Fe	Metal powder	Slight
Fe-55–59 (P)	$FeCl_3$	1–4 mc Fe^{59}/g Fe	In HCl solution	0.1
Fe-55 (P)	$FeCl_3$	0.5–1.5 c/g Fe	In HCl solution	0.1
Fe-59 (P)	$FeCl_3$	0.5–1.5 c/g Fe	In HCl solution	0.1

TABLE VI

(cont'd)

(1) Radioisotope	(2) Compound as Shipped	(3) Specific Activity	(4) Form and Physical Character	(5) Estimate of Probable Fraction Available for Inhalation (%)
Co-57–58 (P)	$CoCl_3$	<0.01 mc/ml	In HCl solution	0.1
Co-60 (I)	Co_2O_3	34 mc/g Co	Powder and/or wire	Slight
Co-60 (P)	$CoCl_2$	0.5–5 c/g Co	In HCl solution	1
Ni-63 (I)	Ni metal	0.35 mc/g Ni	Metal powder	Slight
Ni-63 (P)	$NiCl_2$	5–50 mc/g Ni	In HCl solution	0.1
Cu-64 (I)	Cu metal	300 mc/g Cu	Metal turnings	Slight
Zn-65 (I)	Zn metal	1.9 mc/g Zn	Mossy metal	Slight
Zn-65 (P)1	$ZnCl_2$	75–300 mc/g Zn	In HCl solution	0.1
Zn-65 (P)2	$ZnCl_2$	~5 c/g Zn (CF)	In HCl solution	0.1
Ga-72 (I)	Ga_2O_3	235 mc/g Ga	Powder	Slight
As-73–74 (P)	Chloride or oxychloride	>0.05 mc/ml (CF)	In HCl solution	1 (fumes)
As-76 (I)	As_2O_3	550 mc/g As	Powder	0.1
As-77 (I)	GeO_2	(CF)	Powder	0.1
Se-75 (I)	Se metal	3.3 mc/g Se	Powder	1
Se-75 (P)	Chloride	50–100 mc/g Se	In HCl solution	1
Br-82 (I)	KBr	120 mc/g Br	Crystalline	Slight
Rb-86 (I)	Rb_2CO_3	45 mc/g Rb	Powder	1
Sr-89 (I)	$Sr(NO_3)_2$	0.11 mc/g Sr	Crystalline (fine)	0.1
Sr-89 (P)	$SrCl_2$	>1 mc/ml (CF)	In HCl solution	0.1
SrY-90 (P)	Chlorides	>1 mc/ml (CF)	In HCl solution	0.1
Y-90 (I)	Y_2O_3	115 mc/g Y	Powder	0.1
Y-91 (P)	YCl_3	>1 mc/ml (CF)	In HCl solution	0.1
Zr-95 (I)	$Zr(OH)_4$ or ZO_2	0.05 mc/g Zr	Powder	Slight
Zr-Nb-95 (P)	Oxelate complex	>1 mc/ml (CF)	In oxalic acid solution	0.1
Nb-95 (P)	Nb complex	>1 mc/ml (CF)	In oxalic acid solution	0.1
Mo-99 (I)	MoO_3	7 mc/g Mo	Powder	0.1
Tc-99 (I)	MoO_3	(CF)	Powder	0.1
Tc-99 (P)	NH_4TcO_4	1 mg $Tc^{99} \approx 20\mu c$ Tc^{99}	In weak NH_4OH	0.1
Ru-97 (I)	Ru_2O_3	0.03 mc/g Ru	Powder	0.1
Ru-103 (P)	Chloride	>1 mc/ml (CF)	In HCl solution	0.1
Ru-Rh-106 (P)	Chlorides	>2 c/g Ru (CF)	In HCl solution	0.1

TABLE VI
(cont'd)

(1) Radioisotope	(2) Compound as Shipped	(3) Specific Activity	(4) Form and Physical Character	(5) Estimate of Probable Fraction Available for Inhalation (%)
Pd-109 (I)	Pd metal	220 mc/g Pd	Metal foil	Slight
Ag-110 (I)	$AgNO_3$	5 mc/g Ag	Crystalline	Slight
Ag-110 (P)	$AgNO_3$	100–300 mc/g Ag	In HNO_3 solution	0.1
Ag-111 (I)	Pd metal	(CF)	Metal foil (5 mil)	Slight
Cd-115 (I)1	Cd metal	20 mc/g Cd	Metal, mossy	Slight
Cd-115 (I)2	Cd metal	1 mc/g Cd	Metal, mossy	Slight
Cd-115 (P)	Cd nitrate	5–20 mc/g Cd	In HNO_3 solution	1 (fumes)
In-114 (I)	In metal	70 mc/g In	Metal foil	Slight
In-114 (P)	Chloride	50–150 mc/g In	In HCl solution	1
Sn-113 (P)	Chloride	0.1–1 mc/g Sn	In HCl solution	0.1
Sn-113 (I)	Sn metal		Mossy metal	Slight
Sb-122 (I)	Sb metal	250 mc/g Sb	Metal chunks	Slight
Sb-124 (I)	Sb metal	12 mc/g Sb	Metal powder	Slight
Sb-124 (P)	Sb chloride	500–1500 mc/g Sb	In HCl solution	1 (fumes)
Sb-125 (I)	Sn + Sb metal	(CF)	Mossy metal chunks	Slight
Sb-125 (P)	Sb chloride	~0.01 mc/ml (CF)	In HCl solution	1 (fumes)
I-131 (I)	Te metal	(CF)	Powder	1
I-131 (P)	NaI in Na_2SO_3	5–20 mc/ml (CF)	In Na_2SO_3 solution	0.1
Cs-134 (I)	Cs_2CO_3	60 mc/g Cs	Powder	1 or less
Cs-134 (P)	CsCl	1–3 c/g Cs	In HCl solution	0.1
CsBa-137 (P)	CsCl	1–10 mc/ml (CF)	In HCl solution	0.1
Ba-131 (I)	$Ba(NO_3)_2$	0.25 mc/g Ba	Crystalline and/or powder	0.1
BaLa-140 (P)	Chlorides	>1 mc/ml (CF)	In HCl solution	1 (fumes)
La-140 (I)	La_2O_3	525 mc/g La	Powder	0.1
Ce-141 (I)	CeO_2	7.5 mc/g Ce	Powder	0.1 (dust)
Ce-141 (P)	$CeCl_3$	>1 mc/ml (CF)	In HCl solution	0.1 (fumes)
CePr-144 (P)	$CeCl_3$	>1 m/ml (CF)	In HCl solution	0.1 (fumes)
Pr-142 (I)	Pr_2O_3	550 mc/g Pr	Powder	0.1
Pr-143 (P)	$PrCl_3$	>0.1 mc/ml (CF)	In HCl solution	0.1
Nd-Pm-147 (P)	$NdCl_3$	>0.1 mc/ml (CF)	In HCl solution	0.1
Pm-147 (I)	Nd_2O_3	(CF)	Powder	0.1
Pm-147 (P)	$PmCl_3$	>1 mc/ml (CF)	In HCl solution	0.1
Sm-153 (I)	Sm_2O_3	1000 mc/g Sm	Powder	0.1

TABLE VI
(cont'd)

(1) Radioisotope	(2) Compound as Shipped	(3) Specific Activity	(4) Form and Physical Character	(5) Estimate of Probable Fraction Available for Inhalation (%)
Eu-152–154 (I)	Eu_2O_3	72 mc/g Eu	Powder	0.1
Hf-181 (I)	HfO_2	60 mc/g Hf	Powder	0.1
Ta-181 (I)	Ta Metal	105 mc/g Ta	Metal powder	Slight
Ta-181 (P)	Tantalate	0.5–1.5 c/g Ta	In KOH solution	0.1
W-185 (I)	WO_3	7 mc/g W	Powder	0.1
W-185 (P)	Tungstate	100–400 mc/g W	In KOH solution	0.2
W-187 (I)	WO_3	350 mc/g W	Powder	0.1
Re-185 (I)	Re	1250 mc/g Re	Metal powder	1
Os-191 (I)	Os metal	>3 mc/g Os	Metal powder	0.1
Ir-192 (I)	Ir metal	2.1 c/g Ir	Metal powder	Slight
Ir-192 (P)	K or Na chloroiridiate	1–3 c/g Ir	In HCl solution	0.1
Ir-194 (I)	Ir metal	1700 mc/g Ir	Metal powder	Slight
Au-198 (I)	Au metal	3 c/g Au	Metal foil (1 mil)	Slight
Au-199 (I)	Au and Pt metal	(CF)	Metal foil (3 mil)	Slight
Hg-197 (I)	HgO	200 mc/g Hg	Powder	Slight
Hg-203 (I)	HgO	72 mc/g Hg	Powder	Slight
Hg-203 (P)	Mercury nitrate	50–100 mc/g Hg	In HNO_3 solution	0.1
Tl-204 (I)	$TlNO_3$	1.3 mc/g Tl	Crystalline (fine)	0.1
Tl-204 (P)	Nitrate	50–300 mc/gTl	In HNO_3 solution	0.1
Bi-210 (I)	Bi metal	0.4 mc/g Bi	Granular metal	Slight
FP (P)1	Mixed fission products	1–25 mc/ml	Strong HNO_3 solution	1

(I) Irradiated
(P) Processed
(CF) Carrier Free

TABLE VII

SUMMARY OF THE TWENTY MOST DANGEROUS RADIONUCLIDES LISTED IN ORDER OF DECREASING HAZARD

Inhalation	Injection	Inhalation	
Soluble Radioactive Material		Insoluble Radioactive Material	
The Indicated Organ as the Critical Body Organ		Wound Site the Critical Tissue	Lung the Critical Body Organ	GI Tract the Critical Body Organ
Relative Hazard from Table I	Relative Hazard from Table II	Relative Hazard from Table III	Relative Hazard from Table IV	Relative Hazard from Table V
210 Ac^{227} + dr B	60 Ac^{227} + dr B	$4x10^8$ Ac^{227} + dr	48 Ac^{227} + dr	56 $Ra^{223} \rightarrow Pb^{211}$
9.6 At^{211} + dr T	19 At^{211} + dr T	$7.1x10^7$ Cm^{242}	8.1 Pb^{210} + dr	45 $Ra^{224} \rightarrow Bi^{212}$
4.8 Pb^{210} + dr B	13 Cm^{242} B	$6.7x10^7$ Pb^{210} + dr	8.1 Po^{210}	29 $Th^{228} \rightarrow Bi^{212}$
3.3 Cm^{242} B	11 Pb^{210} + dr B	$6.3x10^7$ Po^{210}	3.6 Ra^{226} + dr	21 $Th^{227} \rightarrow Pb^{211}$
1.6 Po^{210} S	8.3 Po^{210} S	$5.6x10^6$ At^{211} + dr	2.4 Am^{241}	17 Cm^{242}
1.4 I^{131} T	1.9 I^{131} T	$2.0x10^6$ Am^{241}	0.48 At^{211} + dr	16 Pu^{240}
0.9 Am^{241} B	0.53 Th^{234} + Pa^{234} B	$1.9x10^6$ Ra^{226} + dr	0.23 Ba^{140} + La^{140}	6.9 Th^{232} + Bi^{212}
0.3 Ra^{226} + dr B	0.43 Ce^{144} + Pr^{144} B	$1.6x10^6$ Ru^{106} + Rh^{106}	0.23 Ag^{105}	4.6 Am^{241}
0.3 Pu^{239} B	0.42 Ba^{140} + La^{140} B	$1.4x10^6$ Ce^{144} + Pr^{144}	0.21 Ru^{106} + Rh^{106}	1.9 $Ra^{226} \rightarrow Pb^{210}$
0.2 Sr^{90} + Y^{90} B	0.36 Am^{241} B	$1.2x10^6$ Sr^{90} + Y^{90}	0.21 Co^{60}	0.91 $Ac^{227} \rightarrow Pb^{211}$
0.13 Th^{234} + Pa^{234} B	0.34 Sr^{90} + Y^{90} B	$9.1x10^5$ Th^{234} + Pa^{234}	0.21 V^{48}	0.42 $At^{211} \rightarrow Pb^{207}$
0.11 Ba^{140} + La^{140} B	0.28 Ir^{192} S	$7.7x10^5$ Ba^{140} + La^{140}	0.20 Ce^{144} + Pr^{144}	0.37 Ru^{106} + Rh^{106}
0.11 Ce^{144} + Pr^{144} B	0.25 Y^{91} B	$7.1x10^5$ Te^{129}	0.19 Te^{129}	0.34 Ce^{144} + Pr^{144}
0.1 Sr^{89} B	0.20 Ru^{106} + Rh^{106} K	$6.7x10^5$ P^{32}	0.18 Sc^{46}	0.23 Th^{234} + Pa^{234}

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TABLE VII

(cont'd)

Relative Hazard from Table I			Relative Hazard from Table II			Relative Hazard from Table III		Relative Hazard from Table IV		Relative Hazard from Table V	
0.072	Fe^{59}	Bl	0.19	Tm^{170}	B	6.3×10^5	Sr^{89}	0.16	W^{181}	0.19	Y^{90}
0.063	Y^{91}	B	0.18	Sr^{89}	B	6.3×10^5	Rb^{86}	0.14	$Sr^{90} + Y^{90}$	0.18	As^{76}
0.054	Te^{129}	K	0.17	Te^{129}	K	6.3×10^5	Y^{91}	0.14	Ir^{192}	0.17	$Bi^{210} + Po^{210}$
0.048	Tm^{170}	B	0.17	Au^{198}	K	3.7×10^5	Tm^{170}	0.14	$Zr^{95} + Nb^{95}$	0.16	Te^{129}
0.048	$Rh^{106} \rightarrow Ru^{106}$	K	0.12	Pu^{239}	B	3.2×10^5	Ag^{111}	0.13	Tc^{96}	0.16	$Ra^{228} \rightarrow Bi^{212}$
0.048	Au^{198}	K	0.11	Fe^{59}	Bl	3.2×10^5	Te^{127}	0.12	$Th^{234} + Pa^{234}$	0.15	La^{140}

Parent radionuclides with radioactive half-lives less than one-half hour have been excluded in this comparison.

B - Bone, T - Thyroid, S - Spleen, Bl - Blood, K - Kidneys.

The arrow ($\rightarrow$) means the values given include the energies emitted by all the daughter products down to the stable isotope.

APPENDIX

Derivation of general equations of dose resulting from single exposure to a radioisotope:

Case 1. In this case it is assumed that a certain fraction, f, of the radioisotope of concentration (MPC) μc/cc is inhaled at a rate V cc/day or at a rate of (MPC) V μc/day and that it arrives in the critical body organ where it is eliminated exponentially both by radioactive and biological decay. The dose is given by the equation,

$$D = C \int_0^{t_1} \int_t^{t_2} \underbrace{f(MPC)Ve^{-\lambda_r t} e^{-\lambda(\tau - t)}}_{\substack{\text{amount} \\ \text{arriving} \\ \text{in critical} \\ \text{organ}}} dt\, d\tau \qquad (7)$$

$$D = C \int_0^{t_1} \int_t^{t_2} f(MPC)Ve^{\lambda_b t} e^{-\lambda\tau} dt\, d\tau \qquad (8)$$

in which D is the dose in rem following a spill such that (MPI) μc are initially available for body intake for time, t_1, and exposure to time, $\tau - t$. The terms λ, λ_r and λ_b are the coefficients of the total elimination, radioactive decay, and biological decay, respectively. The term MPI = $(MPC)Vt_1$ and

$$D = C \int_0^{t_1} \frac{f(MPC)Ve^{\lambda_b t}}{\lambda} (e^{-\lambda t} - e^{-\lambda t_2}) dt = C \int_0^{t_1} \frac{f(MPC)V}{\lambda} (e^{-\lambda_r t} - e^{-\lambda t_2} e^{\lambda_b t}) dt \qquad (9)$$

$$D = \frac{Cf(MPI)}{t_1 \lambda} \left[\frac{1 - e^{-\lambda_r t_1}}{\lambda_r} + \frac{e^{-\lambda t_2} (1 - e^{\lambda_b t_1})}{\lambda_b} \right] \qquad (10)$$

$C = 3.7 \times 10^4$ (dis/sec μc) 3600 x 24 $\frac{(sec)}{(day)}$ $\sum$ (bE)(RBE)N(Mev/dis) 1.602×10^{-6} (ergs/Mev) 1/m (1/g) 1/100 (g rad/ergs)

$Cf = \frac{51.2\, f \Sigma(bE)(RBE)N}{m}$ rem/day to the critical organ of mass, m, due to 1 μc taken in at time, $t = 0$ (11)

$$MPI = \frac{D \lambda_T t_1}{51.2\, f \Sigma(bE)(RBE)N \left[\frac{1 - e^{-\lambda_T/3}}{\lambda_T} + \frac{e^{-\lambda t_2}\,(1 - e^{\lambda b/3})}{\lambda_b} \right]} \quad (12)$$

$$MPI = \frac{3.12 \times 10^{-3}\, Dm}{f \tau \Sigma(bE)(RBE)N \left[\tau_r (1 - e^{-0.231/\tau_r}) + \tau_b\, e^{-0.693\, t_2/\tau}\,(1 - e^{0.231/\tau_b}) \right.} \quad (13)$$

Case 2. In this case it is assumed the (MPI) of soluble radioactive material enters the body by way of a wound at time $t = 0$ and that fraction f_2' arrives at the critical body organ by way of the blood. Here it remains for a time t_2 and delivers a dose D as indicated by the equation,

$$D = C \int_0^{t_2} f_2'(MPI) e^{-\lambda t}\, dt = \frac{f_2' C (MPI)}{\lambda} (1 - e^{-\lambda t_2}) \quad (14)$$

$$MPI = \frac{1.35 \times 10^{-2}\, Dm}{f_2'\, \tau \Sigma(bE)(RBE)N\,(1 - e^{-0.693\, t_2/\tau})} \quad (15)$$

Case 3. In this case it is assumed the (MPI) of insoluble radioactive material enters the body by way of a wound at time $t = 0$; that all the material remains at the site of the wound where it irradiates the critical tissue of mass $m = 10^{-3}$g, and that it is eliminated from the wound with a biological half-life, τ_b, of 120 days. In this case Equation (15) becomes,

$$MPI = \frac{1.35 \times 10^{-5}\, D}{\tau \Sigma(bE)(RBE)N(1 - e^{-0.693\, t_2/\tau})} \quad (16)$$

Case 4. This case is essentially the same as Case 1 except the lung of mass $m = 10^{3}$ g is always taken as the critical organ, the fraction retained in the lungs, $f = 0.125$, and the biological half-life τ_b is 120 days. Placing these

constants in Equation (13),

$$MPI = \frac{25D}{T\sum(bE)\,(RBE)N\left[T_r(1 - e^{-0.231/T_r}) - 0.231\, e^{-0.693\, t_2/T}\right]} \qquad (17)$$

Case 5. The damage to a portion of the GI tract due to the inhalation of a radioactive isotope is influenced by the radioactive decay rate of the isotope and of the daughters which may replace it, and also by the partial or complete elimination of the isotope and daughters from the GI tract. In most cases the elimination from the GI tract by absorption into the blood stream occurs predominantly while the isotope passes through the small intestine. In this report we compute the damage to the GI tract, taking account of the effect of biological elimination.

We consider the GI tract as composed of four organs--the stomach, small intestine, upper larger intestine, and lower large intestine. We assume one atom of a certain isotope is ingested and that this atom, or the daughters which may replace it, moves through the GI tract spending one hour in the stomach, 4 hours in the small intestine, 8 hours in the upper large intestine, and 18 hours in the lower large intestine. We assume the atom moves at a uniform rate along the intestinal tract. Finally we assume that the elimination from the GI tract occurs uniformly, i.e., at a constant rate during the 4-hour period in the small intestine, and that there is no absorption into the blood stream during the remaining periods of time.

Under these assumptions the atom has a definite position at any time, t, and thus the damage to a specified portion of the GI tract is easily calculated when the number of atoms at any time, t, is known. Suppose the parent isotope has a chain of k daughters. When the isotope or its daughters are passing along a section of the GI tract where no absorption into the blood stream occurs, the number of atoms of each kind is determined by the solution of the following differential equations:

$$\frac{dN_0(t)}{dt} = -\lambda_0^r N_0(t) \qquad (18)$$

$$\frac{dN_i(t)}{dt} = \lambda_{i-1}^r N_{i-1}(t) - \lambda_i^r N_i(t) \qquad i = 1,2, \ldots .k \qquad (19)$$

In Equations (18) and (19) $N_i(t)$ is the number of atoms of the i^{th} daughter which are in the GI tract at time, t, and λ_i^r is the radioactive decay constant for the i^{th} daughter. The subscript, zero, refers to the parent isotope. To completely determine the functions $N_i(t)$, the values of these functions are needed at the time when they entered the section of the GI tract in question. Thus, for the stomach we may take t = o as the time of entry and then $N_0(o) = 1$, $N_i(o) = o$ for $i \geq 1$. The solution of Equations (18) and (19) at any time within the first hour is then given by[10],

$$N_0(t) = e^{-\lambda_0^r t} \qquad (20)$$

$$N_i(t) = \left(\prod_{j=o}^{i-1} \lambda_j^r\right) \sum_{n=o}^{i} \frac{e^{-\lambda_n^r t}}{\prod_{\substack{p=o \\ p\neq n}}^{i} (\lambda_p^r - \lambda_n^r)} \qquad i = 1,2,\ldots k \tag{21}$$

$\prod_{j=o}^{i-1} \lambda_j^r$ means the product of the λ_j^r indicated.

The solutions of Equations (20) and (21) can be extended for arbitrary numbers of atoms of each daughter entering by simply regarding each daughter atom that enters the GI tract as the parent of a somewhat shorter chain of daughters and applying the same formulae (20 and 21) with the corresponding values for k and the λ's. We shall not write here the most general solution which is a rather cumbersome expression. It is, however, easy to write the appropriate solution in any case where k is not very large.

If the atoms are passing through the small intestine, Equations (18) and (19) need to be modified since they neglect absorption into the blood stream. We have assumed that the absorption takes place at a constant rate. Thus, of $N_i(t)$ atoms of the i^{th} daughter which exist at time, t, in the small intestine, i.e., if time is taken in days $1/24 < t < 5/24$, a certain fraction is absorbed per unit time, and we denote this fraction by λ_i^b.

The constant, λ_i^b, plays a role quite analogous to that of the radioactive decay constant, λ_i^r, and we term λ_i^b the biological elimination constant. We put $\lambda_i = \lambda_i^r + \lambda_i^b$ so that if $N_i(t)$ atoms exist at time, t, the number eliminated in time, dt, either through radioactive decay or through absorption into the blood stream, is $N_i(t)\lambda_i dt$. Thus, for $1/24 < t < 5/24$ Equations (18) and (19) become,

$$\frac{dN_o(t)}{dt} = -\lambda_o N_o(t) \tag{18'}$$

$$\frac{dN_i(t)}{dt} = \lambda_{i-1}^r N_{i-1}(t) - \lambda_i N_i(t) \qquad i = 1, 2, \ldots k \tag{19'}$$

and the appropriate boundary conditions are the values of the functions, $N_i(1/24)$, determined by Equations (20) and (21) for $t = 1/24$. It is easily verified that,

$$N_o(t) = e^{-\lambda_o(t - 1)} \tag{20'}$$

$$N_i(t) = \left(\prod_{j=o}^{i-1} \lambda_j^r\right) \sum_{n=o}^{i} \frac{e^{-\lambda_n(t - 1)}}{\prod_{\substack{p=o \\ p\neq n}}^{i} (\lambda_p - \lambda_n)} \qquad i = 1,2, \ldots k$$

is the solution of Equations (18') and (19') with the boundary conditions $N_o(1/24) = 1$, $N_i(1/24) = 0$, $i = 1 \ldots k$. This is easily verfiied by direct substitution and comparison with Equations (20) and (21). Thus, the solution which has the same values at $t = 1/24$ as the formulae (20) and (21) is,

$$N_o(t) = N_o(1/24)e^{-\lambda_o(t - 1/24)} \tag{20''}$$

$$N_i(t) = \sum_{q=o}^{i} N_q(1/24)\left(\prod_{j=q}^{i-1} \lambda_j^r\right) \sum_{n=q}^{i} \frac{e^{-\lambda_n(t - 1/24)}}{\prod_{\substack{p=q \\ p\neq n}}^{i} (\lambda_p - \lambda_n)} \qquad i = 1,2,\ldots k \tag{21''}$$

with $N_q(1/24)$ given by Equations (20) and (21) for $t = 1/24$.

For $5/24 \leq t < 31/24$ Equations (18) and (19) hold, and thus for t in this range, we have,

$$N_o(t) = N_o(5/24)e^{-\lambda_o^r(t - 5/24)} \tag{20'''}$$

$$N_i(t) = \sum_{q=o}^{i} N_q(5/24)\left(\prod_{j=q}^{i-1} \lambda_j^r\right) \sum_{n=q}^{i} \frac{e^{-\lambda_n^r(t - 5/24)}}{\prod_{\substack{p=q \\ p\neq n}}^{i} (\lambda_p^r - \lambda_n^r)} \qquad i = 1,2,\ldots k \tag{21'''}$$

The value of λ_i^b is based on experimental values which determine the amount of an isotope absorbed into the blood stream. Let f_i be the fractional amount of an isotope, i, absorbed into the blood stream. Then λ_i^b is found by solving

$$f_i = e^{-\lambda_i^r} \int_o^{4/24} \lambda_i^b e^{-\lambda_i t}\, dt = \frac{\lambda_i^b}{\lambda_i} e^{-\lambda_i^r}(1 - e^{-\lambda_i 4/24}) = \left(1 - \frac{\lambda_i^r}{\lambda_i}\right) e^{-\lambda_i^r}(1 - e^{-4/24\ \lambda_i}) \tag{22}$$

or,

$$\left(1 - \frac{\lambda_i^r}{\lambda_i}\right)\left(1 - e^{-4/24\ \lambda_i}\right) = e^{\lambda_i^r} f_i \qquad \text{for } \lambda_i = \lambda_i^r + \lambda_i^b$$

Because of uncertainty in the experimental values of f_i, and since our assumptions are not precisely fulfilled, it may happen that

$$e^{\lambda_i^r} f_i > 1,$$

and the equation does not apply. When $e^{\lambda_i^r} f_i$ exceeded 0.95, the latter value was used in place of

$$e^{\lambda_i^r} f_i$$

in Equation (22).

The MPI to give a total damage of 0.3 rem to any given portion of the GI tract can now be readily calculated. The expression,

$$f \sum_{i=o}^{k} N_i(t)\lambda_i^r \Sigma(bE)_i(RBE)_i\, dt \tag{23}$$

represents the total effective energy released in the GI tract in time, dt, due to the inhalation of one atom of parent. The fraction, f, of inhaled atoms arriving in the stomach is taken as 0.625. During the first hour, the radioisotopes are assumed to be in the stomach and so the rem dose to the stomach per atom of parent inhaled is given by,

$$\text{Dose to stomach/atom} = \frac{1.602 \times 10^{-8} f}{2\ m} \int_0^{1/24} \sum_{i=0}^{k} N_i(t) \lambda_i^r (bE)_i (RBE)_i \, dt \qquad (24)$$

A factor of 1/2 has been used since the stomach wall is only irradiated from one side. Then the (MPI) in μc is given by the equation,

$$(MPI)_{stomach} = \frac{0.3\ m\ \lambda_o^r}{25.6\ f \int_0^{1/24} \sum_{i=0}^{k} N_i(t)\, \lambda_i^r (bE)_i (RBE)_i \, dt} \times \frac{\lambda_o^r t_1}{(1 - e^{-\lambda_o^r t_1})} \qquad (25)$$

$$(MPI)_{stomach} = \frac{1.17 \times 10^{-2}\ m}{f T_o^r \int_0^{1/24} \sum_{i=0}^{k} \frac{N_i(t)(bE)_i(RBE)_i}{T_i^r} \, dt} \times \frac{.231}{T_o^r (1 - e^{-.231/T_o^r})} \qquad (26)$$

The fraction on the left of (25), (26) and (28) gives the number of μc actually inhaled and the fraction on the right corrects for radioactive decay before entering the body. Thus MPI is the equivalent amount at time t = o. For other portions of the GI tract, we return to Equation (23) and assume that the energy released in time, dt, is absorbed in the section of the GI tract through which the isotope moved during time, dt. If τ is the total time in the section of the GI tract considered, then the energy released in time, dt, is absorbed in a mass of $m\,dt/\tau$ and thus the rem dose per atom of parent at the site in the intestine is given by,

$$\text{Dose to intestine/atom} = \frac{1.602 \times 10^{-8} f \tau}{2\ m} \sum_{i=0}^{k} N_i(t)\, \lambda_i^r (bE)_i (RBE)_i \qquad (27)$$

The number of μc of parent which deliver 0.3 rem to the site in the intestine is given by,

$$(MPI)_{intestine} = \frac{1.17 \times 10^{-2}\ m}{f \tau T_o^r \sum_{i=0}^{k} \frac{N_i(t)(bE)_i(RBE)_i}{T_o^r}} \times \frac{.231}{T_o^r (1 - e^{-.231/T_o^r})} \qquad (28)$$

The μc of parent which may be inhaled without exceeding the dose of 0.3 rem in any portion of the GI tract is then the minimum of Equation (26) and (28).

$$(MPI)_{GI} = \text{minimum} \left[(MPI)_{stomach},\ (MPI)_{intestine} \right]$$

BIBLIOGRAPHY

1. Handbook-52 of the National Bureau of Standards. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. For sale by Superintendent of Documents, Washington 25, D. C. (1953).

2. ICRP/54/4. Recommendations of the International Commission on Radiological Protection. W. Binks, Secretary, London SW 7, England. (1954).

3. Morgan, K. Z., and Mary R. Ford, Developments in Internal Dose Determinations, Nucleonics 12, 6. June (1954).

4. Handbook-42 of the National Bureau of Standards. Safe Handling of Radioactive Isotopes. For sale by Superintendent of Documents, Washington 25, D. C. (1949).

   Morgan, K. Z., Health Physics, Chapter 9, Handbook on Nuclear Instruments and Techniques. To be published by the National Research Council, Washington, D. C. Handbook editor, E. E. Anderson.

5. Subcommittee on Regulation of Radiation Exposure by Legislative Means of the National Committee on Radiation Protection. (Report in progress) L. S. Taylor, Chairman, National Bureau of Standards, Washington 25, D. C.

6. Evans, Robley D., Physical, Biological and Administrative Problems Associated with the Transportation of Radioactive Substances, National Research Council of the National Academy of Sciences, Washington, D. C. (1951).

7. Drinker, P., and T. H. Hatch, Industrial Dusts, 2nd Edition, McGraw-Hill Publishing Company, Inc., New York (1954).

8. U. S. Atomic Energy Commission, Major Activities in the Atomic Energy Programs, July-December, 1954, p. 93, U. S. Government Printing Office, Washington, D. C., January (1955).

9. Patterson, G. R., from unpublished data compiled by G. R. Patterson of the Oak Ridge National Laboratory. April (1955).

10. Rutherford, E., J. Chadwick, C. D. Ellis, Radiation from Radioactive Substances, Cambridge University Press, New York, London (1951).